SHIP PRODUCTION COMMITTEE
FACILITIES AND ENVIRONMENTAL EFFECTS
SURFACE PREPARATION AND COATINGS
DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCE INNOVATION
MARINE INDUSTRY STANDARDS
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INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

August 1990
NSRP 0320

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

1990 Ship Production Symposium

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1990**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **The National Shipbuilding Research Program, 1990 Ship Production Symposium**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Surface Warfare Center CD Code 2230 - Design Integration Tools Bldg 192 Room 128 9500 MacArthur Blvd Bethesda, MD 20817-5700**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**343**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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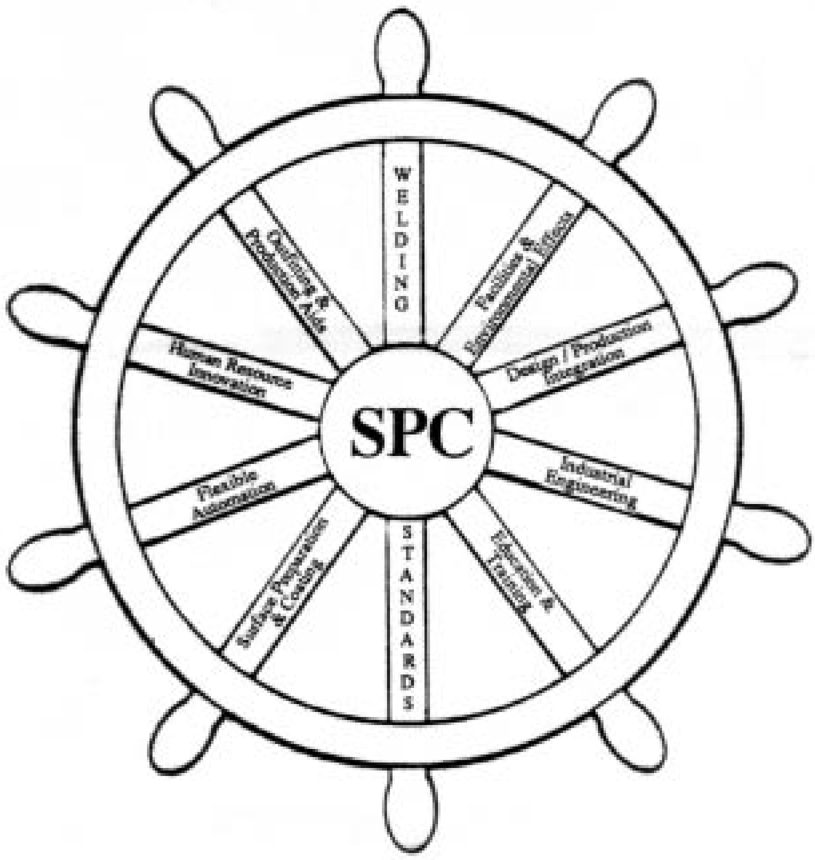

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NSRP
1990 SHIP PRODUCTION SYMPOSIUM

PFISTER HOTEL
Milwaukee, Wisconsin
August 21-24, 1990

Presented by the Great Lakes & Great Rivers section and the Ship Production Committee of the Society of Naval Architects and Marine Engineers

Printed by
The Society of Naval Architects and Marine Engineers
601 Pavonia Avenue
Jersey City, New Jersey 07306

0320

1990 SHIP PRODUCTION SYMPOSIUM
Milwaukee, Wisconsin
August 21-24, l990

TECHNICAL PRESENTATIONS

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee. Wisconsin, August 21-24,199O

Standardization in Ship Structural Design 1A-1

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Abstract

This paper presents two methodologies for the automatic structural design of the midship section of a ship based on the American Bureau of Shipping (ABS) classification rules. The first methodology has as an objective the minimization of the steel required to build the structure of the ship and is based on the solution of a non-linear minimization problem subject to bounds on the variables, linear and non-linear constraints. The second methodology uses a heuristic algorithm based on the use of standard structural shapes to reduce the material cost required for the construction of the ship, while at the same time avoiding a significant penalty in the increase of the structural weight of the ship. Cost data from an actual steel mill are obtained and alternative structural designs for two oil carriers are evaluated according to their material cost and weight differentials. A net present value cost model is then developed to assess the cost advantages of standardization in structural design.

1. Introduction

It is standard practice among ship designers during the preliminary design of a new vessel to use an approach to minimize the structural weight of the ship, since smaller weight results in smaller cost and higher carrying capacity. However, a minimum weight design requires many variations in the properties of the plates and stiffeners composing the ship structure resulting in an increase in the manufacturing cost of the ship. This increase is caused from the use of non-standard plates and stiffener sections, which need to be custom-made in small batches at a higher unit cost.

In this paper we contrast two methodologies for the structural design of a ship. The first methodology minimizes the structural weight of the ship while the second methodology minimizes the cost of the structure of the ship through the use of standardization. To assess the advantages and disadvantages of the two methodologies, a cost model is developed to compare structural costs of new ship structural designs. The main variables to compare are the increased cost of a non-standard ship structure and the reduction in carrying capacity of a heavier standard ship structure. Actual cost data for structural sections from a U.S. steel mill are used to perform these comparisons. The parallel midbody section of a tanker is the basis of our studies on structural design and cost estimation with the two methodologies. The number of variations on the structural properties of the ship structure (plate thickness, stiffener spacing and size) is also varied to assess the effects of using fewer structural shape variations to design the structure of the ship. The American Bureau of Shipping Rules for Building and Classifying Vessels (ABS Rules) are used as a basis for the design of a structurally acceptable ship midship section. A more detailed presentation of the material in this paper can be found in [Kriezis 90].

2. Structural Design Model

It is standard practice among ship designers to design the structure of a ship using classification rules to select the scantlings of the hull structural members. This approach is used also in this work to provide a common framework to compare the two methodologies of minimum weight and minimum cost structural design. The ABS Rules applying to tankers intended for unrestricted ocean service were used [ABS 83].

Since our analysis is based on the structural design of the parallel midbody section of a ship, the design variables considered are limited to the midship hull-girder section modulus and stiffness, shell and deck plating sizes, longitudinal bulkhead sizes, longitudinal stiffener sizes and spacing, and transverse bulkhead spacing. To simplify the analysis the ship is assumed to be designed as a single bottom ship with longitudinal framing with a maximum of two longitudinal watertight bulkheads. There are several types of stiffeners used in ship construction, such as tee, flatbar, offset bulb plates, angles, and channels [Taylor 85]. To reduce the number of unknown elements, we selected to use only tee stiffeners for all the longitudinal elements in the structural design of our tankers. It should be mentioned that tees have a higher cost as compared to other types of stiffeners. Our selection was based more on the information available about different types of stiffeners, than on their cost. The sizing of the transverse bulkheads is not included in our analysis in order to reduce the number of variables in the two structural design methodologies described below.

An idealization of the midship section as used in our algorithms is shown in figure 2-1. The midship section of the ship is split into zones, each of which has its own stiffening arrangement and shell plating. The bottom shell and the deck are each one zone, while the side shell and the longitudinal bulkhead can be split in a number of zones, to

account for the different loading requirements at the different depths in the side of the hull and the oil tanks. For each zone the unknown variables that we want to determine, are the plate thickness (t_p), the stiffener spacing (s), the stiffener web thickness (t_w) and width (w_w) and the stiffener flange thickness (t_f) and width (t_w). These are shown in figure 2-2.

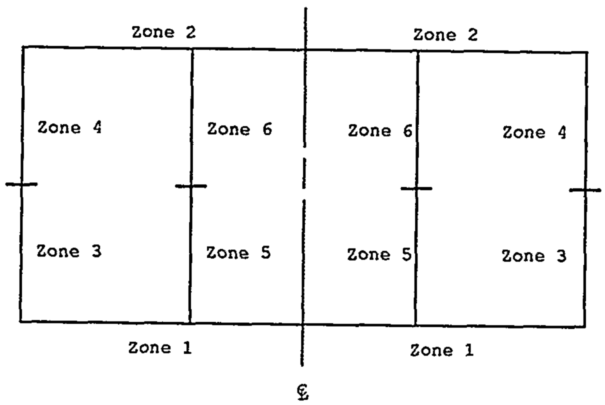

Figure 2-1: Midship Section Idealization

The structural strength of a ship is expressed as minimum requirements for 1) the midship hull-girder section modulus and moment of inertia, 2) the section modulus of longitudinal or bulkhead stiffeners and 3) the thickness of the various plates of the shell, deck or bulkheads of the ship. The empirical formulas specifying these minimum requirements depend on the gross characteristics of the ship and the strength of the material used[ABS 83]. In the calculation of the section modulus of a certain design, the following items are included, under the assumption that they are continuous and effectively developed:

- Deck and shell plating
- Plating and longitudinal stiffeners of longitudinal bulkheads
- All longitudinals of deck, sides and bottom

Shear stresses which may be important for certain classes of vessels, are not accounted for in this study. The net sectional area of the above items is used in the hull-girder section modulus calculation. The effect of isolated openings on these elements is ignored assuming they are small in size.

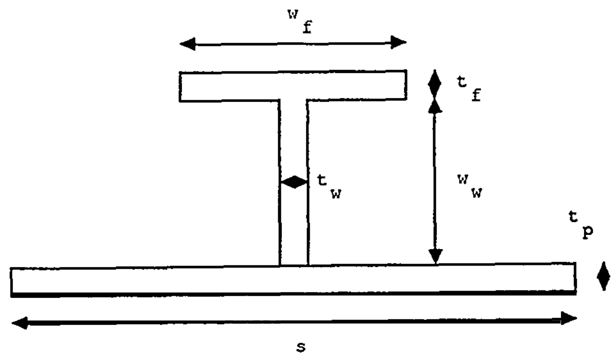

Figure 2-2: Zone Variables

3. Minimum Weight Structural Design

3.1. Problem Formulation

The first methodology used for structural design is based on minimization of the structural weight of the ship structure subject to the constraints imposed by the classification society rules. This problem is formulated as a non-linear programming problem. To simplify the formulation as was stated before, we are concerned with the longitudinal strength elements of the midship section of a tankship and our objective is to size these elements to obtain a midship section that requires a minimum quantity of steel material.

The problem is formulated as a minimization of the midship sectional area of the ship:

$$\textit{Minimize} \quad \sum A_i, \tag{1}$$

where A_i is the sectional area of zone i and contains plate area and tee stiffener area, subject to fixed bounds on the variables and linear and nonlinear inequality constraints imposed by the strength requirements of the Classification society rules.

The first non-linear constraint is as follows:

$$SM_{midship} - SM_{required} \geq 0 \tag{2}$$

where $SM_{midship}$ is the section modulus of the actual midship section of the ship calculated in the current solution vector, while $SM_{required}$ is the required section modulus for the midship section of the ship from the ABS Rules (accounting for the primary loads in the ship structure) [ABS 83]. The section modulus of the midship section of the ship is determined by taking into account all plates and longitudinal stiffeners in the midship section of the ship.

The second set of nonlinear constraints is as follows:

$$SM_i - SM_{i,required} \geq 0 \tag{3}$$

where SMi is the section modulus of a stiffener in structural zone i as calculated from the local plate thickness, stiffener spacing, web thickness and width, and flange thickness and width, and $SM_{i,required}$ is the required section modulus for zone i as specified in the ABS Rules

(accounting for secondary loads in the ship structure) [ABS 83]. If there are n zones specified in the ship, there are n+1 non-linear constraints to satisfy.

In addition, we specify fixed bounds to the variables, to restrict them to reasonable values. From the classification rules there are requirements for a minimum plate thickness for all shell plates to account for local structural loads. These provide the fixed lower bounds for all plate thicknesses, i.e.

$$t_{p,i} > t_{p,i,required} \tag{4}$$

The remaining bounds were determined from empirical data about sizes of plates and stiffeners manufactured in steel mills [American 80]. The values used are as follows:

$$t_{p,i} < 3.2 \text{ cm}, \qquad 0.8 \text{ cm} < t_{w,i},\ t_{f,i} < 4 \text{ cm},$$

$$15 \text{ cm} < W_{w,i}\ W_{f,i} < 90 \text{ cm and}$$

$$0.75 m < S_l < 1.1 m \tag{5}$$

where i indicates the corresponding zone.

A number of linear constraints relating the size of the stiffener web to the size of the stiffener flange were also included in the formulation, to resolve some initial problems with obtaining a manufacturable and structurally adequate solution. A minimization approach on the size of a stiffener tends to increase the size of the stiffener flange, (decreasing the size of the stiffener web) since the flange contributes more to the section modulus of the stiffener and might lead to a stiffener with torsion problems. As a result we require that:

$$w_{w,i} > w_{f,i} \quad \text{and,} \quad t_{w,i} > 0.6 t_{f,i} \tag{6}$$

These approximate values were obtained from stiffener data from the steel construction manual [American 80]. In addition, to avoid buckling of a stiffener web, the web width to web thickness ratio is limited by:

$$w_{w,i} < 60 t_{w,i} \tag{7}$$

An additional constraint which could be imposed is the limit in the transitions allowed between plate thicknesses in neighboring structural zones. Equations 1-7 complete the formulation of the non-linear minimization problem. If there are n structural zones, there are 6n variables to determine, n+l non-linear constraints and 3 n linear constraints to satisfy.

3.2. Solution Method

There is a substantial body of literature dealing with the solution of non-linear constrained optimization problems, and there are several techniques that have been proposed for such problems [Gill 74]. Since the problem is non-linear all algorithms proposed for its solution are iterative in nature and as a result require an initial approximation to the solution. Then information from the first and second derivatives of the objective function and the first derivative of the constraint functions is used to march from the initial approximation to the problem solution. A limitation of non-linear minimization problems is that there is no way to guarantee that the solution obtained represents a global minimum of the minimizing function. As a result different initial approximations may result in different local minimum solutions, or no solutions at all.

For our problem, we selected to use a sequential quadratic programming (SQP) algorithm in which the search direction is the solution of a quadratic programming problem. An explanation of this method can be found in [Gill 74, Gill 81, Kriezis 90, Murray 76]. This algorithm, as implemented in a Numerical Algorithms Group (NAG) routine [NAG 88], is used to solve the minimum structural weight problem formulated above.

4. Structural Design For Standardization

It is desirable during the preliminary structural design of a new ship to try to minimize its structural weight since smaller weight implies less steel required and as a result less material cost. A technique similar to the one presented in the previous section can be used towards such a goal. However, a technique that tries to minimize structural weight for each ship design requires the use of non-standard structural shapes, such as built up plates and stiffener sections. These need to be custom-made in small batches for each particular ship. This results in higher procurement unit costs for these elements, and the cost advantage of a smaller weight design is quickly eliminated.

Our objective was to develop a technique to design the structure of a ship using only standard sizes for plates and stiffener sections, while at the same time attempting to minimize the resulting structure weight from the use of such elements. We have developed a heuristic algorithm, that uses a database of plate sizes and stiffener sections that represent standard products from steel mills and incrementally builds a midship structure by selecting larger plates and stiffener sections, until the section modulus of the midship steel structure and the section modulus of the local stiffener structure in each zone satisfy the ABS Rules. This algorithm is presented in detail in the following section.

4.1. Heuristic Algorithm for Minimum Cost Standardized Design

The first element of the algorithm is the establishment of the database of standard structural shapes. In order to accomplish this the manual of the American Institute of Steel Construction [American 80] was used. It provides characteristics for structural sections which are standard products of U.S. steel mills, as well as information on the standard plate sizes. For our analysis, we used structural tees that are cut from W shapes [American 80]. One source of the tee sections used are obtained by cutting structural I-beams in half, a standard practice among steel mills (half I-beam). The other source of the tee sections used are obtained by removing one of the flanges of a structural I-beam (double web tee). These tees are also standard products, although they cost slightly more than half I-beams, see figures 5-2 and 5-3.

The standard plates available in our database range between l/2 inch to 1 inch thickness every l/16 of an inch and between 1 inch to 1.5 inch thickness every l/8 of an inch. One decision made early in our implementation to reduce the unknown variables for the cost minimization was to make the spacing between the stiffeners in a structural zone an input to the algorithm. This represents another aspect of standardization in the spacing of

elements. Each of the standard plate thicknesses in the database was associated with a a number of standard stiffener spacings (0.75 m, 0.8 m, 0.9 m, 1.0 m) and the resulting structural plate area between stiffeners was computed.

An additional step in the preparation of the database for our algorithm was to sort the elements of the database according to different criteria in increasing order. The two criteria used were structural element area and structural element cost. For plate thickness the result from sorting is identical for both criteria, since cost is proportional to area. For the tee stiffeners the result from sorting is not identical from both criteria, since we have the two types of stiffeners mentioned above (half I-beam, double web tee) with different unit costs per unit area. However, within each tee category cost is still proportional to unit area and the sorting results are identical.

The approach used in our algorithm follows very closely the manual structural procedure which a ship designer uses. To begin with, we look locally in each structural zone and determine the appropriate plate thickness and tee from the sorted database to satisfy the local stiffener section modulus requirements from the rules, and then minimize the area or the cost of the zone sections. The heuristic procedure for this local minimization has the following steps (the algorithm is presented for the databases which are sorted by area):

1. Determine the minimum plate thickness and section modulus required from the rules for the particular zone, t_{res}, SM_{req}.
2. Find the minimum plate thickness t_i in the sorted plate database, which is $t_i \geq t_{req}$.
3. Find the minimum area tee in the sorted tee database with index j, which with plate t_i and the input spacing s_j creates a stiffener with section modulus $\geq SM_{req}$
4. Calculate area of stiffener section A_s, = A_{plate} + A_{tee},
5. Once i, j are found iterate:
   - Use next larger plate in the database (increment i), and find a new j index for the minimum area tee satisfying the section modulus requirement as above. Compute the new area A_s
   - If A'_s, < A_s As, use the new i,j indices and repeat the iteration
   - else, the minimum area for the stiffener in this zone has been found

This algorithm does not require checking of all plates in the database, since the condition A'_s<A_s As is not satisfied for the thicker plates which contribute more area in the stiffener in relation to their contribution to the local section modulus. This algorithm provides a good estimate of the minimum area stiffener for each zone, and our experience is that it results in a balanced tee stiffened plate combination.

Once the initial selection for each zone is performed with the above procedure, the midship section modulus of the resulting structure is computed and is compared to the required midship section modulus from the ABS Rules. If it satisfies the requirement, the current characteristics represent our solution. If it does not satisfy the requirement, the sizes of the structural elements need to be increased and new plates and tees need to be selected. The procedure in this case is the following: If there are n structural zones, we have n plate thicknesses and n different types of tees to select from the database. The current solution is represented as 2 n indices representing elements in the plate and tee databases.

For each element in the solution vector, we select the next larger element in the database (or jump over a few elements in the case of tees) and we compute the relative percentage increase of the midship structure section modulus with the new index versus the old index in relation to the increase in the midship sectional area or the increase in structural cost. Specifically we compute

$$\S i = SMnew/smprevious * A_{T,}previous/{}^{A}T.new$$

where i denotes the element of the solution vector, and A_T denotes the midship sectional area or the midship cost. The relative percentage changes ($\S_i$) for all elements are compared and the one contributing the larger increase is selected to update the solution vector. The updated solution is examined for satisfaction of the section modulus requirement amidships, and if the test fails the above process is repeated until the section modulus requirement is satisfied. In this way a good approximation to the minimum weight or cost standard design is obtained.

Two elements should be noted in the above algorithm. Since the plates at the top and bottom of the ship shell sometimes contribute the largest increase in sectional properties repeatedly (largest δ_i resulting in a ship structure with thick plates, the user is given the freedom to limit the maximum thickness of the ship plates. In this case the plates which reach the thickness requirement during the incremental process described above are not considered in the continuation of this process. The tee database contains stiffeners of varying characteristics and in many cases neighboring elements with approximately the same sectional area contribute differently to the overall midship section modulus. As a result, the incremental process at one of these elements might stop because of the inefficiency of the neighboring element. In these situations the algorithm allows the incremental process to jump over some of the inefficient stiffeners.

The above algorithm represents an excellent methodology for automated structural design of ship midship sections based on standard plates and stiffeners. It uses heuristic arguments to avoid the combinatorial explosion of checking all possible combinations of structural elements and plate sizes to minimize the area or the cost and as a result is very fast. It does not guarantee a minimum but approximates this minimum by trying to simulate the performance of a minimization algorithm. A minimization algorithm moves in the direction of the gradient (maximum change) of the objective function and, in our algorithm, we select to increment the element which increases the midship section modulus the most relative to the increase in the sectional area or the cost.

5. Costs Modeling

One of the objectives of our work was to determine the relative advantages and disadvantages of applying the structural design methodologies presented in the previous sections. In this respect, we want to make a relative cost comparison between designs from the two methodologies. Structural design based on the minimum weight methodology presented in section 3 results in a lower weight midship section made of non-standard parts which have high material cost. Structural design based on the standardization methodology results in a heavier midship section made of parts with low material cost. The savings in material cost in this case should be examined in relation to the potential loss in carrying capacity of the heavier vessel over its lifetime.

Material cost data for plates and stiffeners in standard or non-standard production were obtained from an actual steel mill [Bethlehem 89] These data are presented in figures 5-l to 5-3. Figure 5-l presents the price in US dollars of a metric ton of plating as a function of plate thickness for standard and non-standard plate thicknesses of mild and high tensile strength (HTS) steel. As can be seen in this figure, non-standard plates cost about 20% more than standard plates of comparable thickness. Figure 5-2 presents the price per metric ton of tee stiffeners made from mild steel as a function of the tee sectional area, while figure 5-3 presents similar data for high tensile strength tee stiffeners. In these figures, data for normal tees, tees that are cut from an I-beam (in half), tees that are obtained from an I-beam by removing one flange (double web), and non-standard size tees are shown. As can be seen in these figures, non-standard **structural tees cost about 50%** more than equivalent tees from the other standard categories. Data from these figures were used to evaluate the material cost of different bulk oil carrier midship structural designs. Linear extrapolation was used for elements outside the available range of plate thicknesses and tee sectional areas of figures 5-l to 5-3.

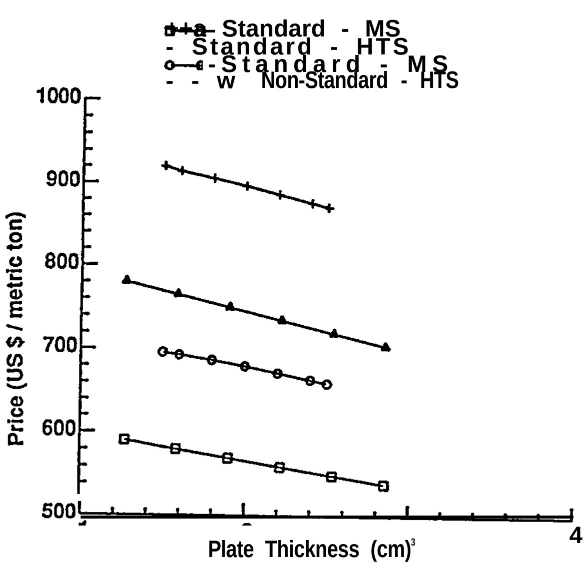

Figure 5-1: Plate Cost Data - All U.S. Prices for May 1989

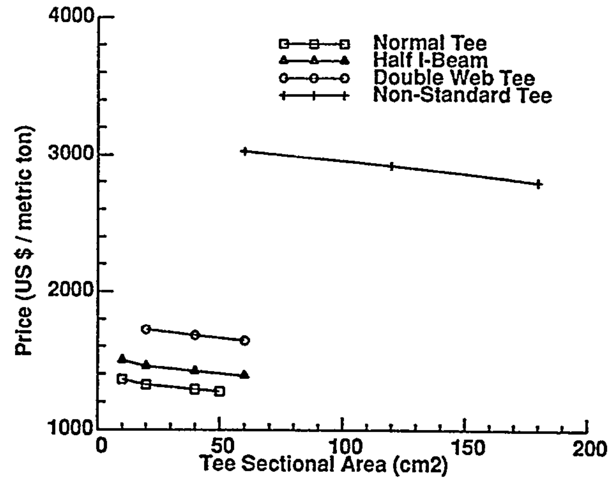

Figure 5-2: Mild Steel Tee Cost Data - All U.S. Prices for May 1989

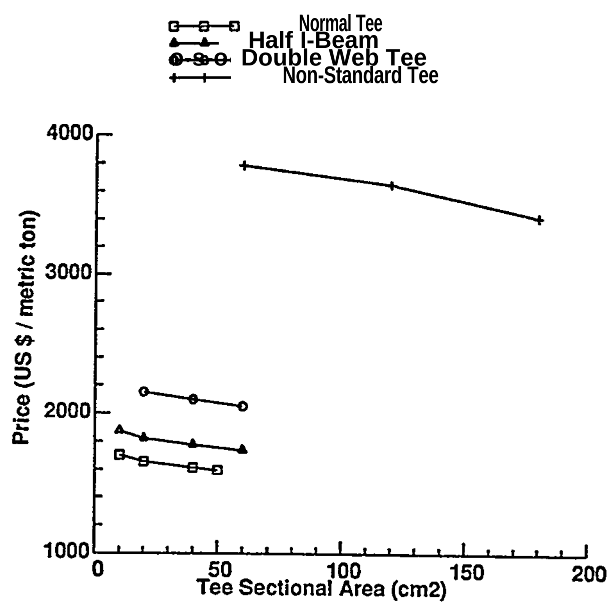

Figure 5-3: HTS Steel Tee Cost Data - All U.S. Prices for May 1989

Once the material cost for the different midship sections resulting from the two methodologies is computed, an approximate cost model is used to evaluate the net present value (NPV) resulting from the use of standardization. This model assumes that the only value differences between the minimum weight design and the standard design are due to the different material costs, and the loss of carrying capacity over the life of the ship of the heavier design (standard design). Accordingly

$$NPV_{standard} = \Delta Material\ Cost - PV_{carr,\ capac.} \quad (8)$$

where

$$\Delta M.C. = L\,(C_{mw} - C_{st})$$

$$PV_{c.c.} = \sum_{i=1}^{N} \frac{\eta\,\Delta Q\, n_t R}{(1+r)^i},\ and$$

$$\Delta Q = L\rho\,(A_{st} - A_{mw})$$

with

C_{mw}, C_{st}, = material cost per unit length of minimum weight and standard design,
L = ship length,
N = life of ship,
n_t = number of trips per year at full load capacity,
R = freight rate per cargo ton assumed constant for the life of the ship,
ΔQ = loss in carrying capacity per trip,
η an efficiency factor to account for the costs of additional cargo capacity,
A_{st} A_{mw} = midship sectional area of standard and minimum weight design,
p = 7.85 mton/m^3, steel density and
r = rate of return adjusted for inflation.

Our design analysis also predicts the length of stiffener welding required for each of the designs. If this is different for the two designs due to the different stiffener spacing in the various ship zones, the cost of additional welding required can be also added in the material costs in equation 8 according to

$$\Delta C_{welding} = L\,R_w\,(L_{w,mw} - L_{w,st})$$

where

R_w, = the cost in material and labor of welding one meter of stiffener and
$L_{w,mw}$, $L_{w,st}$ the length of tee fillet welding required per m of midship section for the minimum weight and standard designs respectively.

The above model provides a reasonable estimate of the relative cost advantages and disadvantages of designing a particular ship for minimum weight versus designing this ship for standardization.

6. Applications

6.1. Procedure & Assumptions

This section presents two example applications of the structural design methodologies presented above. The material cost of different designs is compared and the advantages of standardization are assessed. The procedure followed in the analysis of each of the two examples is given below: 1) the midship section of the ship is split in the minimum of four structural zones (bottom shell, deck shell, side shell, longitudinal bulkhead) and standard designs for various stiffener spacings are determined using the heuristic algorithm of Section 4; 2) the standard designs are then used as initial approximations to solve the minimum weight design problem by solving the non-linear programming problem outlined in Section 3; 3) the number of structural zones is then increased by splitting the ***zones*** in the side shell and the longitudinal bulkhead and new standard designs and minimum weight designs are produced. The resulting designs are then compared and their material costs contrasted

Some preliminary information about our analysis is provided below. The database of tee stiffeners used in the standardization analysis contained 116 different tees, half of which were tees cut from I-beams (half tees) and the other half were I-beams with one flange removed (double web tees). The spacing of tranverse frames assumed in the analysis of both examples was 4 meters. The results from the analysis are presented in tables 6-l through 6-7. Each of these tables presents the size of the structural elements in each zone, the required and achieved section moduli for the stiffeners and the ship midship section, the midship sectional area, the plate and tee material cost as computed from the methodology of the previous Section, and the required amount of tee fillet welding.

For the net present value calculation to determine the advantages of standardization the following assumptions were used. The base trip was assumed to be 11,000 miles round trip. For such a trip, a tanker moving at 12 to 14 knots requires a minimum of 35 days. Thus, a maximum of 10 trips per year was allowed in the calculation. The average cost of tanker transportation of oil for an 11,000 mile tip in 1982 was approximately $l.l5/barrel or about $8.5/mton [Rawlinson 83]. This value changes depending on the market conditions and is usually lower for bigger ships. Values of $10 and $20/mton were used in our model. The efficiency factor n accounting for the costs of additional carrying capacity was assumed to be 1.0 (no costs). The life of the ship was assumed to be 20 years and the rate of return adjusted for inflation was assumed to be 15%. For the welding costs estimation the material and labor cost of welding one meter of tee stiffener was assumed to be $5/m weld (10 min at $15/hr labor, doubled for the material).

6.2. Large Crude Carrier (121,000 mton)

The first application of the two structural design methodologies is performed on a large crude oil carrier (LCC) with approximately 121,000 mton deadweight displacement. This ship is based on a standard Series 60 hull form [Todd 54] and its gross characteristics are given in table 6-l. Mild steel is used throughout the structural design of this vessel.

Length (LBP)	228.6 m (750.0 ft)
Breadth (Mid)	40.8 m (133.9 ft)
Depth Wid)	20.5 m (67.3 ft)
Draft (Design)	16.3 m (53.5 ft)
Block Coefficient (C_b)	0.8044
Deadweight	121,000 tons

Table 6-1: Large Crude Carrier Gross Characteristics

Tables 6-2 and 6-3 present the design of the standardization algorithm for this ship, when four structural zones are used in the analysis for a stiffener spacing of 1.00

meter and 0.8 meters. Tables 6-4 and 6-5 present minimum weight designs obtained with initial approximations the designs in tables 6-2 and 6-3. Several things can be observed in these tables. The two standard designs have similar midship structural areas and about the same cost. However, the smaller tee spacing design requires **25%** more tee welding. The two minimum weight designs have also similar midship structural area, although the costs in this case vary as one design requires larger stiffeners and smaller plates. It is characteristic of the minimum weight algorithm results that the sizes of the structural elements are adjusted so that the non-linear section modulus constraints are approximately satisfied at their lower bounds. Minimum weight designs also favor larger spacing between the stiffeners (1.1 m spacing is the upper bound of allowed spacing in the minimization algorithm). It should be noted that as the required section modulus for stiffeners depends on the spacing of the stiffeners which is a variable in the minimization algorithm, these values differ for different spacings. Comparing the results in tables 6-2 and 6-4 we see that the minimum weight design saves 10% of the midship structural area of the standard design. This loss is equivalent to a loss of 900 mtons carrying capacity (1% of the 100,000 mton ship capacity). The savings in construction of the standard design has a present value of $8614 per m of midship section, while the present value of the loss of carrying capacity is $2555 per m of midship section at a freight rate of $l0/mton ($5110 at a freight rate of $20/mton). The net benefit of standardization is $6059 per m of midship section ($3504 in the other case), which could be equivalent to a maximum of $1.25 million savings for the whole ship if the savings are assumed to continue along the ship length ($0.7 million at double the freight rate).

Zone	tp (cm)	tw (cm)	ww (cm)	tf (cm)	wf (cm)	s (m)
Pottom	2.38	1.40	50.19	2.22	31.34	1.00
Deck	2.38	0.89	50.19	1.14	16.51	1.00
Side	2.06	1.17	64.49	1.63	25.30	1.00
Bulkhead	1.75	1.31	57.30	2.22	23.C2	1.00

zone	Required SM (cm3)	Achieved SM (cm3)
Bottom	3316.	4489.
Deck	386.	1672.
Side	2250.	4040.
Bulkhead	2369.	4057.

Required Midship Section Modulus - 34.21 m3
Achieved Midship Section Modulus - 34.39 m3

Midship Steuctural Area - 5.33 m2

Plate cost - s 16000. per m midship section.
Tee Cost - s 22342. per m midship section.
Required tee fillet welding = 327 m per m midship section

Table 6-2: Standard Design Characteristics for LCC With Tee Spacing = 1 m and 4 Structural Zones

Zone	tp (cm)	tw (cm)	ww (cm)	if (cm)	wf (cm)	s (m)
Bottom	2.54	1.31	57.30	2.22	23.02	0.80
Deck	2.22	0.89	50.19	1.14	16.51	0.80
Side	2.06	1.09	57.30	1.50	1-86	0.80
Bulkhead	1.75	1.31	32.30	2.11	25.44	0.80

zone	Required SM (cm3)	Achieved SM (cm3)
Bottom	2653.	4134.
Deck	308.	1647.
Side	1800.	2578.
Bulkhead	1895.	2090.

Required Midship Section Modulus - 34.21 m3
Achieved Midship Section Modulus - 34.49 m3

Midship Structural Area - 5.42 m2

Plate cost - $ 15995. per m midship section
Tee cost - $ 23088. per m midship section.
Required tee fillet welding - 409 m per midship section

Table 6-3: Standard Design Characteristics for LCC With Tee Spacing = 0.8 m and 4 Structural Zones

Zone	tp (cm)	tw (cm)	WY (cm)	tf (cm)	wf (cm)	s (m)
Bottom	2.35	0.91	51.85	1.52	33.42	1.02
Deck	2.87	0.80	26.52	1.33	17.84	1.10
Side	2.05	0.84	50.18	1.39	25.92	1.10
Bulkhead	1.68	0.85	50.75	1.41	27.36	1.10

zone	Required Sm (cm3)	Achieved SM (cm3)
Bottom	3388.	3388.
Deck	424.	859.
Side	2475.	2470.
Bulkhead	2606.	2601.

Required Midship Section modulus - 34.21 m3
Achieved Midship Section modulus - 34.21 m3

Midship Structural Area - 4.81 m2

Plate cost - $ 19659. per m midship section
Tee cost - $ 27417. per m midship section
Required tee fillet welding - 303 m per m midship section

Table 6-4: First Minimum Weight Design Characteristics for LCC With 4 Structural Zones

Tables 6-6 and 6-7 present a standard design and a minimum weight design, when eight structural zones are used. The minimum weight design is obtained again with the initial approximation being the standard design. Several things can be observed in these tables. The midship structural areas are reduced as compared to the structural results with the four zones, since the loading in the additional zones is smaller. This reduction is small, indicating that the point of diminishing returns is reached fast in allowing more variations in the structural elements of the ship midship section. Comparing the results in tables 6-6 and 6-7 we see that the minimum weight design in this case saves 9% of the midship structural area of the standard design. The savings in construction of the standard design has a present value of $8326 per m of midship section, while the present value of the loss of carrying capacity is $2309 per m of midship section at a freight rate of $l0/mton ($4618 at a freight rate of $20/mton). The net benefit of standardization is $6017 per m of midship section ($3708 in the other case), which is about equivalent to a maximum of $1.2 million savings for the whole ship if the savings are assumed to continue along the ship length ($0.75 million at double the freight rate).

zone	tp (cm)	tw (cm)	ww (cm)	tf (cm)	wf (cm)	s (m)
Bottom	2.26	1.14	57.30	1.90	23.01	1.09
Deck	2.33	0.93	50.19	1.17	16.51	0.75
Side 1	2.05	0.95	57.29	1.48	17.88	1.10
Bulkhead 1	1.68	1.40	32.35	2.34	25.48	0.98

zone	Required SM (cm3)	Achisved SM
Bottom	3623.	3622.
Deck	289.	1696.
Side 1	2475.	2415.
Bulkhead 1	2312.	2312.

Required Midship Section Kodulus - 34.21 m3
Achieved Midship Section Wodulus - 34.11 m3

Midship Structural Area m 4.91 m2

Plate cost - $ 18487. per m midship section
Tee cost - S 35634. per m midship section
Required tee fillet welding - 342 m per m midship section

Table 6-5: Second Minimum Weight Design Characteristics for LCC With 4 Structural Zones

zone	tp (cm)	tw (cm)	ww (cm)	tf (cm)	f (cm)	s (m)
Bottom	2.38	1.40	50.19	2.22	31.34	1.00
Deck	2.54	1.31	25.10	2.12	21.22	1.00
Side 1	2.06	1.17	64.49	1.63	25.30	1.00
Side 2	2.06	1.17	32.25	1.63	25.30	1.00
Side 3	2.22	0.89	25.10	1.14	16.51	1.00
Bulkhead 1	1.75	1.31	57.30	2.22	23.02	1.00
Bulkhead 2	1.43	1.17	32.25	1.63	25.30	
Bulkhead 3	1.43	1.09	28.65	1.50	17.88	1.00

zone	Required SH (cm3)	Achieved SM
Bottom	3316.	4489.
Deck	386.	1428.
Side	2250.	4040.
Side 2	1430.	1714.
Side 3	609.	678.
Bulkhead 1	2369.	4057.
Bulkhead 2	1505.	1666.
Bulkhead 3	641.	1038.

Required Midship Section modulus - 34.21 m3
Achieved Midship Section modulus - 34.29 m3

Midship Structural Area - 5.07 m2

Plate cost - $ 15965. per m midship section
Tee Cost - $ 18193. per m midship section
Required tee fillet welding - 327 m per m midship section

Table 6-6: Standard Design Characteristics for LCC With Tee Spacing = 1 m and 8 Structural Zones

6.3. Very Large Crude Carrier (230,000 mton)

The second application of the two structural design methodologies is performed on a very large crude oil carrier (VLCC) with approximately 230,000 mton deadweight displacement. The principal dimensions of this ship are based on an example of a VLCC in [Taggart 80] and its gross characteristics are given in table 6-8. High tensile strength steel is used throughout the structural design of this vessel. Reference [Taggart 80] also presents a structural design for this ship, which is shown in table 6-l 1 and figure 6-l and is compared with our designs.

zone	tp (cm)	tw (cm)	ww (cm)	tf (cm)	wf (cm)	s (m)
Bottom	2.31	1.00	57.79	1.47	30.91	1.10
Deck	3.19	0.80	25.53	1.01	18.08	1.08
Side 1	2.05	0.89	53.64	1.49	21.03	1.10
Side 2	2.05	0.80	48.00	1.20	17.01	1.10
Side 3	2.05	0.80	28.63		16.30	1.10
Bulkhead 1	1.68	0.83	50.06	1.18	33.36	1.10
Bulkhead 2	1.37	0.80	48.00	1:28	18.02	1.10
Bulkhead 3	0.92	0.80	30.02	0.97	16.82	1.10

zone	Required SM (cm3)	Achieved SM (cm3)
Bottom	3648.	3644.
Deck	416.	686.
Side 1	2475.	2474.
Side 2	1573.	1573.
Side 3	670.	670.
Bulkhead 1	2606.	2601.
Bulkhead 2	1656.	1655.
Bulkhead 3	705.	705.

Required Midship Section Modulus - 34.21 m3
Achieved Midship Section Modulus - 34.15 m3

Midship Structural Area - 4.60 m2

Plate cost - $ 19366. per m midship section
Tee cost - $ 23258. per m midship section
Required tee fillet welding - 299 m per m midship section

Table 6-7: Minimum Weight Design Characteristics for LCC With 8 Structural Zones

Length (LBP)	306.2 m (1004.5 ft)
Breadth (Mid)	48.7 m (159.8 ft)
Depth (Mid)	24.5 m (80.6 ft)
Draft (Design)	18.9 m (61.9 ft)
Block Coefficient (Ch)	0.835
Deadweight	230,000 tons

Table 6-8: Very Large Crude Carrier Gross Characteristics

Table 6-9 presents the design of the standardization algorithm for this ship, when four structural zones are used in the analysis for a stiffener spacing of 1 meter. Table 6-10 presents the minimum weight design obtained with initial approximation the design in table 6-9. Comparing the results in tables 6-9 and 6-10 we see that the minimum weight design saves 7.5% of the midship structural area of the standard design. This loss is equivalent to a loss of 1400 mtons carrying capacity (0.7% of the 210,000 mton ship capacity). The savings in construction of the standard design has a present value of $30,082 per m of midship section, while the present value of the loss of carrying capacity is $2850 per m of midship section at a freight rate of $l0/mton ($5700 at a freight rate of $20/mton). The net benefit of standardization is $27,232 per m of midship section ($24,382 in the other case), which could be equivalent to a maximum of $8 million savings for the whole ship if the savings are assumed to continue along the ship length ($7.25 million at double the freight rate).

The ship analyzed in this example, has been used in [Taggart 80] to illustrate the application of classification rules in the structural design of ships. As a result [Taggart 80] presents a structural design for this ship, which has been obtained using the ABS rules manually. Figure 6-l presents the midship section of this ship as designed in

[Taggart 80]. The structure in figure 6-1 has a linear variation in the tee properties of the side shell and the longitudinal bulkheads. In order to compare with our methodology, this design has been approximated with 8 zones and the result is shown in table 6-11. It should be noted, that this design uses flatbar stiffeners for the deck area as can be seen in table 6-11. Tables 6-12, 6-13 and 6-14 present a standard design and two minimum weight designs, when eight structural zones are used. The minimum weight designs are obtained using as initial approximations the standard design and the design in [Taggart 80] as shown in table 6-11. Comparing the standard design with the manual design in [Taggart 80], we observe that the standard design results in 3% savings in the midship structural area over the manual design. If we assume also that the manual design does not use standard elements, then the cost of the manual design is significantly higher than the cost of the standard design. The two minimum weight designs shown in tables 6-13 and 6-14 have very similar characteristics, although they were started from significantly different initial approximations. Compared to the structural results for the designs with fewer structural zones, the midship structural areas of the standard and the minimum weight designs are reduced as expected This reduction is small indicating that we reach the point of diminishing returns fast in allowing more variations in the structural elements of the ship midship section. Comparing the results in tables 6-12 and 6-13 we see that the minimum weight design in this case saves 7% of the midship structural area of the standard design. The savings in construction in this case has a present value of $26,713 per m of midship section, while the present value of the loss of carrying capacity is $2457 per m of midship section at a freight rate of $lO/mton ($4914 at a freight rate of $20/mton). The net benefit of standardization is $24,256 per m of midship section ($21,799 in the other case), which is about equivalent to a maximum of $7.25 million savings for the whole ship if the savings are assumed to continue along the ship length ($6.5 million at double the freight rate).

Zone	tP (cm)	tw (cm)	ww (cm)	tf (cm)	wf (cm)	s (m)
Bottom	2.06	2.11	39.85	3.56	40.28	1.00
Deck	2.86	1.65	25.10	2.63	31.60	1.00
Side	2.38	1.45	64.59	2.36	25.58	1.00
Bulkhead	1.90	1.54	57.30	2.44	32.65	1.00

zone	Required Sm (cm3)	Achieved Sm (cm3)
Bottom	5892.	6319.
Deck	602.	2466.
Side	3998.	5559.
Bulkhead	4209.	5783.

Required Midship Section Modulus - 62.63 m3
Achieved Midship Section Modulus - 63.45 m3

Midship Structural Area - 7.79 m2

Plate cost - $ 26426. per m midship section
Tee cost - $ 41792. per m midship section
Required tee fillet welding - 391 m per m midship section

Table 6-9: Standard Design Characteristics for VLCC With Tee Spacing = 1 m and 4 Structural Zones

zone	tp (cm)	tw (cm)	ww (cm)	tf (cm)	wf (cm)	s (m)
Bottom	2.93	1.21	69.07	2.01	33.22	1.07
Deck	3.20	1.53	29.77	2.40	29.77	1.09
Side	2.25	0.95	57.21	1.40	43.18	1.10
Bulkhead	1.78	0.97	58.29	1.37	46.58	1.10

zone	Required SM (cm3)	Achieved SM (cm3)
Bottom	6328.	6328.
Deck	654.	2630.
Side	4398.	4397.
Bulkhead	4630.	4625.

Required Midship Section Modulus - 62.63 m3
Achieved Midship Section Modulus - 62.63 m3

Midship Structural Area - 7.21 m2

Plate cost - $ 34420. per m midship section
Tee cost - $ 64040. per m midship section
Required tee fillet welding - 359 m per m midship section

Table 6-10: Minimum Weight Design Characteristics for VLCC With 4 Structural Zones

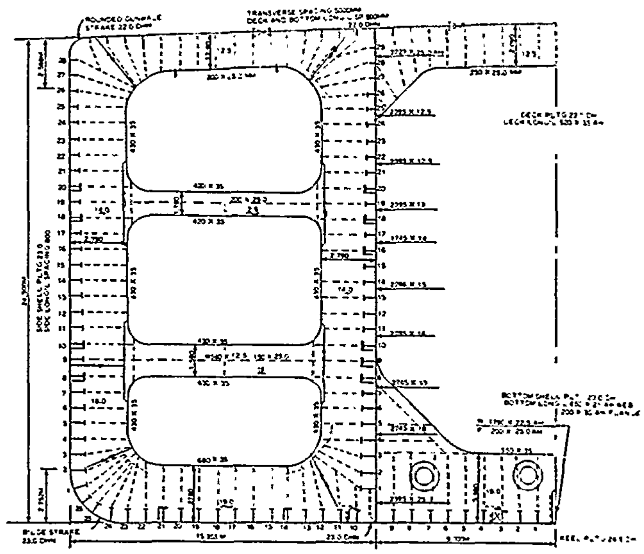

Figure 6-1: Midship Section Manually Designed Based on ABS Rules [Taggart 80]

Zone	tp (cm)	tw (cm)	(cm)	tf (cm)	wf (cm)	s (m)
Bottom	2.35	2.10	66.00	3.00	20.00	0.90
Deck	2.30	3.50	53.00		0.	0.90
Side 1	2.30	1.25	74.00	1.60	15.00	0.80
Side 2	2.30	1.15	54.00		15.00	0.80
Side 3	2.30	1.15	44.00	2.50	15.00	0.80
Bulkhead 1	2.50	1.25	79.00	1.60	10.00	0.80
Bulkhead 2	1.60	1.15	54.00		15.00	0.80
Bulkhead 3	1.80	1.15	44.00	1.60	12.50	0.80

zone	Required SM (cm3)	Achieved SM (cm3)
Bottom	5303.	6258.
Deck	542.	2880.
Side 1	3199.	3734.
Side	1973.	2977.
Side 3	747.	1740.
Bulkhead 1	3367.	3551.
Bulkhead 2	2077.	2879.
Bulkhead 3	186.	1533.

Required Midship Section Modulus - 62.63 m3
Achieved Midship Section Modulus - 62.74 m3

Midship Structural Area - 7.61 m2

Place cost - $ 30895. per m midship section
Tee Cost - $ 89984. per m midship section
Required tee fillet welding - 461 m per m midship section

Table 6-11: Manual Design Characteristics for VLCC with 8 Structural Zones - Approximation of Figure 6- 1

zone	tp (cm)	tw (cm)	wW (cm)	tf (cm)	Wf (cm)	s (m)
Bottom	2.06	1.59	86.28	2.39	30.42	1.00
Deck	2.86	1.83	50.19	2.92	31.77	1.00
Side 1	2.38	1.45	64.59	2.36	25.58	1.00
Side 2	2.38	1.31	57.30	2.22	23.02	1.00
Side 3	2.38	1.09	28.65	1.50	17.88	1.00
Bulkhead 1	1.90	1.54	57.30	2.44	32.65	1.00
Bulkhead 2	1.43	1.40	50.19	2.22	31.34	1.00
Bulkhead 3	1.27	1.09	28.65	1.50	17.88	1.00

zone	Required SM (cm3)	Achieved SM (cm3)
Bottom	5892.	9160.
Deck	602.	5925.
Side	3998.	5559.
Side 2	2466.	4166.
Side 3	934.	1081.
Bulkhead 1	4209.	5783.
Bulkhead 2	2596.	4294.
Bulkhead 3	983.	1028.

Required Midship Section Modulus - 62.63 m3
Achieved Midship Section Modulus - 63.16 m3

Midship Structural Area - 7.39 m2

Plate cost - $ 25420. per m midship section
Tee cost - $ 43055. per m midship section
Required tee fillet welding - 391 m per m midship section

Table 6-12: Standard Design Characteristics for VLCC With Tee Spacing = 1 m and 8 Structural Zones

zone	tp (cm)	tw (cm)	ww (cm)	tf (cm)	wf (cm)	s Cm)
Bottom	2.68	1.21	70.18	2.02	33.29	1.10
Deck	3.12	1.40	31.59	2.33	31.59	0.75
Side 1	2.25	0.97	58.26	1.52	38.48	1.10
Side 2	2.25	0.81	48.38	1.27	34.20	1.10
Side 3	2.25	0.80	41.09	0.80	17.37	1.10
Bulkhead 1	1.78	0.97	58.41	1.51	42.03	1.10
Bulkhead 2	1.43	0.81	48.65	1.25	38.00	1.10
Bulkhead 3	0.91	0.80	42.93	0.80	19.02	1.10

zone	Required SM (cm3)	Achieved SM (cm3)
Bottom	6481.	6480.
Deck	452.	2801.
Side	4398.	4392.
Side 2	2713.	2711.
Side 3	1027.	1027.
Bulkhead 1	4630.	4628.
Bulkhead 2	2855.	2855.
Bulkhead 3	1081.	1081.

Required Midship Section Modulus - 62.63 m3
Achieved Midship Section Modulus - 62.62 m3

Midship Structural Area - 6.89 m2

Plate cost - $ 32721. per m midship section
Tee cost - S 62437. per m midship section
Required tee fillet welding - 397 m per m midship section

Table 6-13: First Minimum Weight Design Characteristics for VLCC With 8 Structural Zones - Initial Approximation from Standard Design

zone	tp (cm)	tw (cm)	ww (cm)	tf (cm)	wf (cm)	s (m)
Bottom	2.60	1.41	48.54	2.35	48.54	1.10
Deck	3.20	2.10	26.99	2.23	26.99	0.79
Side 1	2.25	0.99	59.31	0.96	57.57	1.10
Side 2	2.25	0.81	48.64	0.95	45.29	1.10
Side 3	2.25	0.80	41.58	0.80	16.86	1.10
Bulkhead 1	1.78	1.04	62.23	0.94	58.21	1.10
Bulkhead 2	1.43	0.84	50.66	1.01	44.05	1.10
Bulkhead 3	0.91	0.80	43.38	0.80	18.55	1.10

zone	Required SM	Achieved Sm (cm3)
Bottom	6481.	6470.
Deck	474.	2149.
Side	4398.	4321.
Side 1	2713.	2712.
Side 3	1027.	1027.
Bulkhead 1	4630.	4537.
Bulkhead 2	2855.	2855.
Bulkhead 3	1081.	1081.

Required Midship Section Modulus - 62.63 m3
Achieved Midship Section Modulus - 62.57 m3

Midship Structural Area - 6.88 m2

Plate cost - $ 32131. per m midship section
Tee cost - $ 64324. per m midship section
Required tee fillet welding - 391 m per m midship section

Table 6-14: Second Minimum Weight Design Characteristics for VLCC With 8 Structural Zones - Initial Approximation from Manual Design

7. Conclusion

As was seen from the examples presented in the previous section, the heuristic algorithm developed for automating the use of standnrdization in ship structural design leads to substantial savings in the costs required to build the structure of a ship at only a small expense in the loss of cargo carrying capacity of a slightly heavier ship. Both automated methodologies are certainly superior to the manual process of ship structural design as was seen in the second example using the design from [Taggart 80].

The standardization methodology could be easily espanded to treat alternate ship designs and also to treat double bottoms, transverse sturctural elements and other parts of the ship and not just the midship section. It is evident from our analysis, that it is worthwhile for ship designers to consider the costs of the structural materials used in the design of a ship, since wise selection of standard elements which are manufactured cheaply can lead to significant savings in the material structural cost of a ship.

Acknowledgments

The technical support of Professor E. G. Frankel, my thesis supervisor, is deeply appreciated. The computer facilities of the Ocean Engineering Design Laboratory at M.1.T were used for implementation of this work.

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium, Ptister Hotel. MuWaukee. Wisconsin, August 21-24.1990

Manufacturing Lead Time-A Factor To Consider During Planning and Acquisition of Navy Ships

1A-2

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ABSTRACT

NAVSEA Shipbuildig Support Office, Philadelphia, PA provides current Manufacturing Lead Time information to Navy planners, designers and acquisition mnagers responsible for the timely procurement of the latest design Navy ships. Lead time information is critical to effective budqeting and on-time delivery of basic mterial, hull mechanical and Electrical Compcnents and Combat Systems. ThiS paper will address the methodology for solicitation, statistical consolidation and final assessment of information provided by over 1300 domestic primary and secondary manufacturs. Early detection of lead time change provides a basis for remedial action whereby critical paths may be selected, schedules altered, or substitutions provided. The paper will further address the status of the United States Industrial Base capacity to provide these materials, components and systems and compares the current industrial base with its status five and ten years ago. Loss of domestic capacity has resulted in sole or single source procurement and in some cases sole dependence upon a foreign source for critical subcomponents. The ability of United States manufacturers respond to peacetime programs and potential surge or mobilization requirements will also be examined.

ORGANIZATION

The NAVSEA Shipbuilding Support Office (NAVSHIPSO) is functionally responsible to Deputy Commandeer for Acquisition, Planning and Appraisal,NAVSEA 90. NAVSHIPSO is located in the Philadelphia Naval. Shipyard and is under the administrative control of its commander. NAVSHIPSO supports NAVSEA in the execution of its shipbuilding and major weapons acquisition programs throug manufacturing engineering and industrial.planning. It also provides Industrial Preparedness Planning functions for these program. In addition, NAVSHIPSO provides Support to NAVSEA by performing mobilization planning functions assigned to NAVSFA by the Office of the chief of Naval Operations and other Navy and Defense Department authority. Navy programs are analyzed to determine manufacturing facility and resource requirements. The industrial base is evaluated to determine its ability to support current and projected Navy programs and to identify problem areas and action required to resolve these issues. NAVSHIPSO supports acquisition and industrial preparedness planning with the development of ship and eguipment prcduction plans and analysis of individual contractor capabilities, performances,andmanufacturingleadtimes. NAVSHIPSO maintains statistical and historical records On Navy ships time of construction through final disposition.

MMANUFACTURING LEAD TIMES

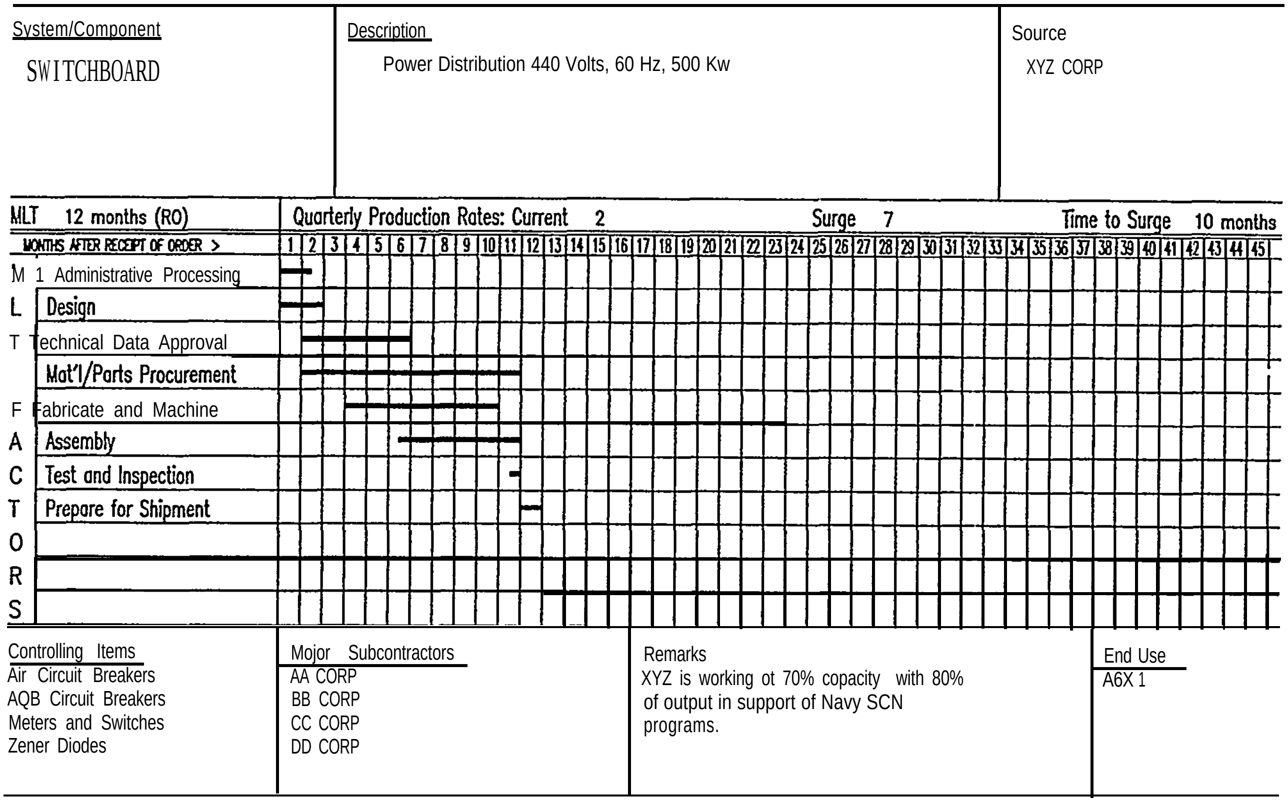
A major element of industrial base planning and evaluation responsibility is the determination of manufacturing lead time (MLT) forecasts. MLT in formation is essential for effective financial planning/budgeting and to support schedule adherence for on-time delivery of shipboard Basic Material, Hull Mechanical and Electrical Components and Combat Systems. Early detection of future MIT change provides a basis for remedial action whereby critical paths my be selected schedules altered or substitutions provided. Specifically, within NAVSHIPSO, MLTs form the core of various industrial assessment and shipbuilding program related reports, including the following

o SYSTEM/EQUIPMENTS MANUFACTURING LEAD TIME STUDIUES -An annual document which provides a breakdown of factors considered in a manufacturing process and result in quoted MLT for a specific component or system. DATA IS presented in a time phased Gantt chart format and includes an overview of subcompopnents/manufacturers production rates, and ship end use. Figure 1 depicts a typical study.

0 SPECIAL STUDIES- Reports are prepared on subjectS of particular importance to the Navy's shipbuilding program. Typical topics have included anchor chain,ball bearings, forgings, diesel engines, composite materials, periscopes, torpedo tubes and electric propulsion. Table 1 lists recently completed and planned studies. Some of these studies, such as ball bearings (quiet), *anchor chain and* forgings,havedirectlyresultedin purchase restrictions to US and canadian sourceS. Others, diesel enqines, strategic

materials, periscopes, propellers and electric motors have highlighted sole sourcing conditions or dwindling domestic industrial base capabilities concerns and have provided recommended plans of action to alleviate possible mobilization production constraints.

o ADVANCE PIANNING STUDIES(APS)-APS are prepared for various Ship Acquisition Program Managers providing estimates of required contract and construction periods, manning levels requirements and production need *requirements* of principal longleadtimecomponentsandcontrolling items. A typical APS consists of:



BUSINESS SENSITIVE

Fig. 1 - MANUFACTURING LEAD TIME STUDY

TABLE 1. SPECIAL STUDIES

Conpleted

Electric Motors
Electronic Equipment MFG
  Foreign Dependency
  Productivity Trends
Large crankshafts
Tuebochargers
Arresting Gear
Deigaussing system
Propellers
Anchor chain
Forgings
periscopes
Global Positioning System
Dehydrators
MIl-SPEC Air circuit Breakers
Large Diesel Engines
Retooling study
Capacity Utilization Trends
Manpower and Labour Issues
Main Propulsion Machinery
Critical Forging Restrictions
Anchor Chain Restrictions

In-Process

Electric Propulsion
  Propulsion Motors
  Prime Movers
Composite Material
Shafting
Strategic Materials
Machine Tools
Noise Quiet Bearings
IAMPS/RAST
Torpedo Tubes
Satellite Comunications
AN/UYQ-21 Display System
Over-The-Horizon Radar
MK86 Gunfire Control
Commnd/Control/Dxision
AN/WSN-5 Navigation System
Navy Use of Composites

Shins Data Sheet - Provides proposed ships principal physical characteristics: length, beam, draft, displacement, type of propulsion plant, shaft horsepower, mission and any special systems or requirements peculiar to the ship design.

Assumptions and *Notes* - Such as availability of drawings and specifications prior to contract award; long lead time and controlling items which may require advance procurement, and source(s) of MLTS and land-on-ship times.

Program summary -Chronological sequence of milestones prior to ship delivery, including contract award, procurement of controlling and long lead time items by both the shipbuilder and government and start construction dates.

Construction Rationale - Provides justification for construction period which includes analysis of actual construction schedules of similar type ships and construction methods and facilities of possible shipbuilders.

Erection Schedule - Narrative description of major events listed chronologically by month.

Manday Estimates - Daveloped by NAVSHIPSO and are calculated by construction, method of construction and ship characteristics.

Advance Planning Lead Time study (APLTS)- Provides MLT, land-on-ship time, quantity, procuring agent, type of specification of long lead time and controlling items.

PUBLICATION OF MANUFACTURING LEAD TIMES- (MLTPUB)

This dOCUMENTS is issued annually and provides a twelve month projection of MLTS for Hull, Mechanical and Electrical Ship Components, Basi material and Combat Systems utilized by shipbuilders performing Navy related work. The publication is divided into six parts. Each is described below as to function and use. An excerpt from part l is *shown as* Figure 2.

Included in parts 1 and2 is the range column which is the composite of all MLTS provided to NAVSHIPSO by manufacturers for each item. Two numbers separated by a hyphen represent the lowest and highest MLTS provided for U.S. Government Specification repeat orders. For example, if the numbers, 16-18 appear, it indicates NAVSHIPSO validated manufacturer responses ranging from 16-18 months. Both the current lead time and the change from the previous issue are provided. For example, 14(-3) indicates a current lead time of fourteen months and a decrease of three months from the previous seventeen months figure. Items added since the previous issue are identified by a single asterisk (*) to the left of MLT column(s).

when a lead time is "not applicable" to a specific item, "NA" has been inserted in the respective column. in general, "NA" in the repeat order column indicates the item has not been produced to date or is not related to a *known* production line. "NA" in the initial order column indicates.theitemis a Qualified Products List (QPL) component, a single source item or standardized to the point that a new design is not anticipated.

Commnercial marine specification lead time is designated "NA"[1] when components are purchased solely under government specifications.

Part 1- Hull, Mechanical and Electrical

All lead times in the Hull, Mechanical and Electrical (HM&E) Ship Components section have been derived by NAVSHIPSO from Navy procurement experience and data obtained directly from manufacturers. The lead times under "U.S. Government SPECS" apply to ship components purchased under Federal or Military Specifications; where possible, specification numbers are listed. The lead times under "COMMERICAL MARINE SPECS apply to ship components which generally meet commercial standards specified by various technical associations including;

American Bureau of Shippig Rules For Building and Classing Steel Vessels
U.S. Coast Guard Electrical Engineering Regulations (OG-259)
U.S. Public Health Service Handbook on Sanitation of Vessel Construction (Standards of Sanitation and Rat Proofing For the Construction of Vessels), except that sheathing requirementS are not applicable
Institute of Electrical and Electronics Engineers, Incorporated (IEEE) Standard No. 45 (Recommended Practice for Electric Installations on Shipboard)
The National Electrical Code (NEC)
The National Electrical Manufacturers Association (NEMA) Standards
The American Gear Manufacturers Association (AGMA)
The American Society for Testing and Materials (ASTM)
The American Society of Mehanical Engineers (ASME)
United States of America Standards Institute (USASI)
American Standards Association (ASA)
National Institute of Standards and Technology (NET)

Manuafacturing Lead Times are a general guide for timely placement of purchase orders. The lead time is defined as the interval between the date a manufacturer accepts a firm order and the shipment date of the first complete production unit.

The lead time estimate does not include any allowance for the administrative time required to develop purchase specifications, to prepare prccurement requisitions, or to conduct negotiations prior to award of production

contracts. Additionally, because of various factors such as material and physical specifications, end use, temperature and pressure conditions, qualifications apply to the following components;

propallers - Design is not included in initial order of solid propellers, add two months for prairie masher
Shafting - Iead times include finish machining
Valves -Add two to four months for 100% radiography

time necessary for the manufacturer to design, obtain plan approval, tool, procure material and subcomponents manufacture, assemble, condut tests, and prepare the first production unit for shipment. When a Military Specification requires testing of the prototype or preproduction model at government facilities or a private laboratory, an allowance is included in the lead time. If floating shock platform testing is required, two to four months should be added to the listed lead time.

PART 1

HULL. MECHANICAL, AND ELECTRICAL SHIP COMPONENTS

COMPONENT	MIL SPEC	U S GOVERNMENT SPECS REPEAT ORDER	RANGE	INITIAL ORDER	COMERCIAL MARINE SPECS REPEAT ORDER	INITIAL ORDER
		(IN MONTHS)			(IN MONTHS)	
ANCHOR						
LIGHTWEIGHT ALL SIZES / RATINGS ETC	MIL-A-15707 ML-A-15708	4	4	6	4	6
STOCKLESS ALL SIZES / RATINGS ETC	ML-A-22575	4	4	4	4	4
ANNOUNCING SYSTEM						
AUDIO COMMUNICATION INTERCOM	MIL-I-22560 MIL-I-24078	11	10-12	12	9	10
LOUD HAILER		9	9-10	10	9	10
PUBLIC ADDRESS	MIL-A-21577	11	10-12	12	10	10
VOICE ENHANCEMENT 1MC - 59MC	MIL-A-21577	11	10-12	12	NA	NA
ARRESTING GEAR SYSTEM						
MOD 3 ALL SIZES / RATINGS ETC		54	54	NA	NA	NA

Fig. 2 - MANUFACTURING LEAD TIME PUBLICATION

The lead times stated herein assume that purchasers indicate, on their procurement documents, the order is certified for national defense use under Defense Priorities and Allocations System regulations and pass on the authorized rating assigned (i.e., DO-A3, DX-A3) . The use of ratings on contracts and orders is mandatory through all tiers of procurement.

Thelead times listed for ship components are shown for both Initial Order and Repeat order. NAVSHIPSO definitions for each type order follows;

Initial Order - The time to design and produce a component within the state of the art (without extensive research and development)by a menufacturer who has not previously Produced. the It includes the

Repeat Order- The lead time required, after a complete break in production, to produce an item identical, except for minor changes, to one made on a previous order. Generally, the manufacturing lead time of a repeat order is less than that required on an initial order since design and approval of plans will be considerably less and the aptterns,tools and dies [redacted] required for production are available. It is assumed the components previously shock tested and accepted will not require retesting.

part 2- Basic Material

Lead times as for basic material have been derived by NAVSHIPSO from exeprience and data obtained from producers, foundries, and distributors. They are based on the-minimum

amount of the basic material (i.e., mill lot) the producer will accept as a firm order to justify production. The lead times listed are for basic material purchased in accordance with Federal or Military Specifications or comparable commercial specification.

The lead time estimate for basic material is defined as the interval between the date that the producer accepts firm order and the shipment date. lead times include the time necessary for certification of chemical content and tests as stipulated in the specification. However it is emphasized lead times do not apply for less than mill lot orders of basic material are generally available from inventories maintained by distributors and suppliers.

It must be recognized that forgings and costings are not standard production and lead times are subject to negotiation with the individual foundres and forge shops. the lead times shown are for general guidance only. specific lead times for individual ordes are dependent upon the complexity of the customer's drawing specification sizes quantities amount of machinig required, and other factors. Approximately eight weeks should be added to the listed lead times for Number products that require fire-retardant salting, drying or preservation oiling treatment.

part3 -combat/syatem/Equipments

The selected combat systems/Eq[redacted]s herein can be purchased commercially as contractor furnnished Mareria1 (CFM)for Navy Shipbuilding programs; however, for the most part ,they are procured as Government furnished Material (GFM). Teh applicationj Navy model designation has been included in the item description for specific identification. The conditioms for procurment parallel the criteria listed for part 1, HM&E Ship components-

Part 4 - Combat Systems/Equipments T[redacted] Programs

The combat system/Equipments herein are available for the most part as a "turnaround " or "one for one" exchange as GEM. The applicable Navy model designator has been included in the item description for specific identification. The indicated period is the nominal"turnaround" time required by the manufacturre or refurbishment agency.

Part 5 -selected manufacturing lead Time Trends

Manufacturing lead Time Trends are provided for three general categories: Hm&E ship component , Basic Material and Combot system. For each category, typical historical representative samples of repeat order lead times were chosen. Ten year history of selected items is presented both numerically and graphically .

Part6 -participating manufacturers

This part us and canadian manufacturers, by product,that assist NAVSHIPSO by providing lead time information. Without this invaluable assistance, the publication would not be possible. In the **state/province (ST/PROV)** column the following **Canadian provincial postal** abbreviations are **used as required.**

AB-Alberta	NT-Northwest Territories
Bc- British columbia	ON-ontaro
MB-Manitoba	PE-prince Edward **Island**
NB-New Brunswick	PQ-Quebec
NF-Newfoundland	sK-saskatchewan
NS-Nova scotia	YT-Yukon Territory

canadian manufactures MlT information was solicited during l989 and appears for the first time in the January l990 publication.

MANUFACTURING LEAD TIME DETERMINATION METHODOLOGY

MLTS are obtained by large data collection efforts from five sources.The most significant being an annual office of Managementand Budget approved mail solicitation to 1300 us and Canadian mnufacturers, figure3. as can be seen, other key data elements such as capacity, utilization rates, workload [redacted]on, employment levels and value of shipmenrt are also collected. After initial solicitation is received, most of the data, with exception of "company Data" elements, preprinted on subsequent solicitations in order to reduce the burden on respondents. since 1980 the solicitation fomat and the data base have both grown **substantially** In l980 solicitations consisted **only of basic**MLT data elements. In I984 capacity utilization was added and in 1986 the scope was expanded to include most of the factors of 1990 solicitation. The prccess used to collect, validate and analyze MLTS is substatially automated. It is a process within the modelling system "ALIAS",a NAVSEA approved computer system. This automated process includes;

Manufacturing lead Time production Solicitations (MLT solicitations) - This form is preprinted with previously supplied "product Data" (MLTS and Production Rates) for selected components, material or system that manufacturers are, have or are capable producing for Navy shipbuilding programs. MLT solicitations are mailed to each manufacturirer for pen/ink change, additions or deletions and return to NAVSHIPSO. A cognizant Industrial specialist, after reviewing and validating the data will typically find changes in themanufacturers address, point -of -contact, or "company/prouct Data" elements which are incorporated into ALLAs. on occasion, manufacturewrs respond with a narrative containing exceptions or

qualifying remarks to the MLTs presented. Examples are MLT increases for testing (environmental, stress, shock), special processes (heat treating, plating, inspections, etc) or exclusion of certain subcomponents (government furnished, long lead time or foreign sourced).

The industrial specialist is responsible for interpreting the remarks and adjusting the MLT quote according to circumstances reported and Navy procurement methods and requirements. When all responses deemed required are received, generally averaging 90%, and data validation and entry is complete, NAVSHIPSO

SAMPLE

DATE: 20 AUG 90

CAGE	COMPANY	CONTACT	TTTLE	TELEPHONE
xx001	XYZ CORP	H. SPECH	PRESIDENT	(215)897 3161

PRODUCT DATA — PRODUCTION RATES — MONTHS TO REACH

DESCRIPTION/GOVT SPEC	MLT PERIOD MONTHS	GOVT RO/IO	COMML	CURRENT	SURGE	MOB	MONTHS TO REACH	UNIT OF ISSUE
CIRCUTT BREAKER,AIR, ACB/MIL-C-17587Iic-17587		6/8	6/7	234	360	500	8	12 FACH

DEFINITIONS:

MLT = MANUFACTURING LEAD TIME
GOVT = PRODUCED TO GOVERNMENT/MILITARY SPECIFICATIONS
COMML = PRODUCED TO COMMERCIAL MARINE SPECIFICATIONS
RO = REPEAT ORDER MLT
IO = INITIAL ORDER MLT
CURRENT = NUMBER OF UNITS BEING PRODUCED TO MEET CURRENT CONTRACTUAL COMMITMENTS.
SURGE = ACCELERATED PRODUCTION WITH EXISTING FACILITIES AND EQUIPMENT IN A PEACETIME ENVIRONMENT - NO DECLARED NATIONAL EMERGENCY. ONLY PEACETIME PROGRAM PRIORITIES WILL BE AVAILABLE.
MOB = FULL EXPANSION RESULTING FROM ACTION BY CONGRESS AND THE PRESIDENT TO MOBILIZE ALL UNITS AND THE MATERIAL RESOURCES NEEDED FOR THESE UNITS. PRODUCTION OF NON-ESSENTIAL CONSUMER GOODS MIGHT DECLINE SIGNIFICANTLY AND MODIFIED DESIGNS WOULD PROBABLY BE USED TO MAXIMIZE PRODUCTION RATES.
UNIT OF ISSUE = PHYSICAL MEASUREMENT OR COUNT OF A PRODUCT.
CAPACITY UTILIZATION = RATIO OF CURRENT PRODUCTION TO SURGE PRODUCTION.
VALUE OF SHIPMENTS = VALUE IN CURRENT DOLLARS OF ALL PRODUCTS SHIPPED DURING LAST ACCOUNTING YEAR.
REMARKS = ANY SIGNIFICANT AMPLIFYING INFORMATION ON PRODUCTION UNITS, PRODUCT MIX AND/OR CONCURRENT OR INDIVIDUAL PRODUCTION EFFORTS.

COMPANY DATA:

REMARKS:
PRODUCTION RATES ARE BASED ON PRODUCING ALL ITEMS CONCURRENTLY

1. CAPACITY UTILIZATION = 72.00 %

2. CURRENT EMPLOYMENT LEVEL = 200

3. WORKLOAD DISTRIBUTION PERCENTAGES:

NAVY= 2 00 % ARMY= 20%AIR ______

OTHER GOVT= 5% COMMRCIAL-= 3 00 % FOREGEN= 5%

4. VALUE OF - = SHIPMENTS =$6.000,000.

Fig. 3 - MANUFACTURING LEAD TIME PRODUCTION SOLICITATION

personnel lWillbegintheprocesS to generate . the final information to be printed in the Publication of manufacturing Lead Time .

The first step is to perform a regression' analysis of MLTS, product by product, using a standard deviation to determine control limites limits.

The resultant figure is then subjected to a validation proccess in industrial specialist campares it to recent performances by Navy supportive manufacturers and MLT data from other 0sources. -. The primary sources for recent actual MLTS(performance) are:

• Material Monitoring guides (MMG) -An MMG is derived by NAVSHIPSO from shipbuilding Material odering schedules for ships under construction. Each summarizes the most important components/systems and provides as a minimum, the following information;

Item Nomenclature

manufacturer (or other source, such as a distributor)

Purchase Order Award Date

Required-in-Yard Date

Land-on-Ship Date

Scheduled Delivery Date

Actual Delivered Date

• Plant Load Report (PIR) - A PIR provides a manufacturer' Navy shipbuilding/repair orderbord. It is Preparead by by NAVSHIPO === and ccompleded by the manufacturing, often with the assistance of the cognizant Defense contract Administration Service representative. are essential validation tools. A typical PIR provides;

Item Nomenclature

contract -

Customer

Data of order

Order Required Date

Estimated Shipment Date

Actual Shipment Date

• On-site Industrial Plant Surveys (Plant surveys)grs) -Plant Surveys conducted to collect and validate MLTS, capacity, facility and manpower data relative to Navy shipbuilding, canversion and repair- demands for ship components, material and system. information previously provided by the manfacturers **obtained** from other sources s is verified and other data is obtained. figure (4) NAVSHIPSO Industrial profile,details data elements and obtained during the course of a plant Survey.

•various Government and commercial Documents and publications -NAVSEA prime contracts are reviewed and monitored for performance appraisal. pertinent MLT information ids also obtained frm other Navy,DOD and government sources and commerical publications including purchasing Magazine and metalworking News.

The last step in the MLTPUB producttion procces. is development of a twelve month MLT forecast. all data previously obtained, validated and analyzed is then weight mitigating factors in order to develop a forecast for publication. projected requirements versus capacity, lobor, subcomponent,mterial and labor availability, and capacity utilization utilization are considered and compared. t**uences on MLT growth or MLT forecasts for ships' main** propulsion gas tubine engines, , for example, are not only based on demand but also but by MLTs ofkeysubcamponents such as shaft bearings. . Therefore, even though demand for the turbine may not be sufficiently strong enough to extend MLTs, longer MLTS may develop because of demands on the bearing producers by other industries. although NAVSHIPSO has been successful in thus this type Of approach in collecting, validating and fo[redacted]ng MLTS,, the office is developine and implementing macroecconomic forecasting model, Navy Econometric System for predicting Relevant Industrial Trends (NESPRIT). It will be used to enhance our ability to project MLTs Industrial capablity in support of NAvy shipbuilding programs ten years into the future.

Upon analysis completion, forecasts are enterad into ALIAS,with the exception of the memo, table of contents and intro introductison, camera ready reports of PARTS 1 throught 6 are Prepared directly from ALIAS report generators. These are forwarded to a coammercial publisher via Navy publication and printing service Branch office .

Since its inception in l955, the MLTPUB has been expanded from 20 pages to 280 pages and is currently distributed to 1522 uS manufacturing and government offices and 95 canadian manufacturers and government office. Among the government recipier recipients are:

Department of Defence- Army, Navy, Air Force,Defence Logistics ~agencY

Departments of Commerce and Transportation

Office of Management and Budget

Federal Emergency Management Agency

Canadian Defense Production Office

NAVSHIPSO INDUSTRIAL PROFILE

A. COMPANY NAME: ______________________ DATE: __________
DIVISION: ______________________
COMPANY ADDRESS: ______________________ ______________________
(STREET PO BOX) (CITY, STATE, ZIP)

CAGE: __________ PIN: __________
CONTACT NAME: ______________________ TITLE: ______________________
PHONE: ______________

B. GOVERNMENT REPRESENTATIVE: ______________

C. TOTAL EMPLOYMENT LEVEL: ______________

CATEGORY / PERSONNEL		PERSONNEL / SHIFT (1)	(2)	(3)	HRS/ DY	DyS/WK
OFFICE	______	____	____	____	______	______
ENGINEERING	______	____	____	____	______	______
PRODUCTION	______	____	____	____	______	______

D. UNION [redacted]: ______________
CONTRACT EXPIRATION DATE: ______________

E. CAPABILITIES FOR: FORGINGS ______________ CASTINGS ______________

F. FACILITIES:
(1) TOTAL PLANT ACREAGE: ______________ OCCUPIED: ______________
(2) PLANT FLOOR SPACE: ADMINISTRATIVE: ______________ R&D: ______________
(Square Feet)
PRODUCTION: ______________ TEST: ______________
(3) FUEL USED: INDUSTRIAL: ______________ HEATING: ______________
(4) UTILIZATION
PERCENTAGE OF EXISTING PLANT CAPABILITY CURRENTLY IN USE: ______________%
PERCENTAGE OF CURRENT WORKLOAD FOR:
(a) NAVY ______________% (d) OTHER GOVERNMENT ______________%
(b) AIR FORCE ______________% (e) COMMERCIAL ______________%
(c) ARMY ______________% (f) FOREIGN ______________%

G. CURRENT NAVY CONTRACTS: (Direct or Indirect)

CONTRACT OR P.O. NUMBER	PURCHASER	AWARD DATE	ITEM PROVIDED	NAVY PROGRAM SUPPORTED

H. PAST NAVY CONTRACTS: (Direct or Indirect)

CONTRACT OR P.O. NUMBER	PURCHASER	AWARD DATE	ITEM PROVIDED	NAVY PROGRAM SUPPORTED

I. PRODUCTION CAPABILITY:

ITEM DESCRIPTION	MLT (W or M) GOVT RO/IO	COML RO/IO	QUARTERLY PRODUCTION RATES CURR	NORM	SURGE	MOB	MONTHS TIME TO REACH SURGE	MOB	UNIT OF ISSUE

J. SPECIAL LABOR REQUIREMENTS:

SKILL/TRADE/ PROFESSION	NUMBER OF PERSONNEL CURR	NORM	SURGE	MOB	TYPE TRAINING PROVIDED (OJT, TUITION AID, (APPRENTICESHIP ETC.)

K. SUBCONTRACTORS: (Major, Sole Source, Unique, Overseas, Etc.)

NAME/ADDRESS/ CITY/STATE/ZIP	ITEM/SERVICE PROVIDED	MLT (MONTHS)	ITEM SUPPORTED	MANUFACTURING SITE

L. PLANT EQUIPMENT: (Major/special; machine tools, inspection, test, etc.)

QTY	MANUFACTURER	TYPE	CAPACITY	YEAR BUILT	ORIGIN

FOREIGN DEPENDENCY FOR PARTS/SERVICE:

M. COMMENTS:

Fig. 4 - NAVSHIPSO INDUSTRIAL PROFILE

MLT TRENDS

Although the shipbuilding supporting industrial base has contracted over the past decade, MLTs for some Basic Material and HM&E components have generally decreased while Combat Systems/components increased. Tables II and III provide ten year overviews of selected items' MLTs. HM&E and Basic Material MLT improvements are attributed mainly to the aggressive Navy shipbuilding program which consisted of a large number of follow-on orders (large lot procurement) for DD 963, FFG 7, AO 177, CG 47, LSD 41, T-AO 187, SSN 688, SSBN 726, T-AGOS 1 and LCAC classes of ships and craft. This building program afforded many manufacturers opportunities to;

Improve workforce learning curve

Improve processes, workflow and testing methods

Develop capable subtier material suppliers and subcontracted work support

Improve plant equipment and facilities

Improve planning and scheduling

Stabilize design

All of these conditions affected HM&E and Basic Material MLTs during the 1980's.

MLTs increases in the same time period are attributable to:

- o Increased backlog at prime or subtier level for such components and material as castings, forging, bearings, motors, plate and sheet.
- o More stringent specifications requiring increased testing or requirements; such as reduced airborne and structureborne noise levels, improved efficiency, weight and volume reductions and increased mean-time-between failure.
- o Change orders which interrupted production schedules
- o Material/subcomponent costs

However, for Combat Systems MLT increased slightly in the last decade due mainly to longer MLTs for material and subcomponents, minor changes in regulations and long lead time material purchasing practices, alternate sourcing (initially) and complex systems reaching full production status.

TABLE II

MANUFACTURING LEAD TIME TRENDS FOR SHIP COMPONENTS
(IN MONTHS)

	JAN 1981	JAN 1982	JAN 1983	JAN 3984	JAN 3985	JAN 3986	JAN 1987	JAN 1988	JAN 1989	JAN 1990
BLOWERS	14	15	13	11	9	9	8	8	8	9
BOILERS	13	13	12	11	10	10	8	8	8	9
CONDENSERS	16	15	3.3	12	11	11	8	10	10	10
CONSOLES	14	14	13	13	12	13	10	11	11	10
DISTILLING PLANTS	14	13	11	11	11	11	10	11	11	11
ENGINES	12	12	11	9	9	9	7	8	8	9
REDUCTION GEARS	20	19	18	19	19	20	17	15	20	19
GENERATOR SETS	15	15	14	13	13	13	13	13	13	14
POWER SUPPLIES	17	17	13	12	12	9	9	8	8	8
PROPELLERS	12	12	11	10	9	9	10	10	12	14
SHAFTING	10	8	7	8	7	6	6	6	7.	8
SWITCHBOARDS	12	12	12	12	11	10	9	10	9	9
TURBINES	23	24	20	20	22	23	20	20	20	20

TABLE III

MANUFACTURING LEAD TIME TRENDS FOR MAJOR COMBAT SYSTEMS (IN MONTHS)

	JAN 1981	JAN 1982	JAN 1983	JAN 1984	JAN 1985	JAN 1986	JAN 1987	JAN 1988	JAN 1989	JAN 1990
COMBAT DlRECTION	14	14	17	17	18	18	18	17	16	17
COMMNICATIONS	ll	12	l3	l3	12	13	13	12	11	10
ELECTRONIC	14	13	17	18	18	17	15	16	17	17
NAVIGATIONAL	13	15	14	14	14	15	17	16	17	16
RADAR	14	14	14	14	15	15	16	16	15	16
SONAR	14	15	15	14	13	12	13	12	15	16
WEAPONS	23	23	22	21	20	21	22	21	23	23
WEAPONS DIRECTION	24	22	20	20	20	19	20	22	23	24

IMPACT OF MLT ANALYSIS

PERHAPS THE MOST Concise assessment of Of MLT analysis is that which appears in reference (1) . "Defense system typically exhibit lead time volatility. in the discussions of scheduling it is noted that the start date for contractor activity is normally based on a set back from the required completion date The set back is dictated by the operation flow time and the material and component lead time when the lead time is in error, two possible problems exist. IF the lead time estimate is excessive, the funds requirement will be established unecessarily early. This may lead to an overstatement of the lead time and could result in funds being drawn unneccessarily from other areas of need If the lead time estimate is understated, specific contractaor activities could experience a start date that will not support the required delivery date wihtout the expenditure of of premium effort, resulting in higher than necessary program cost or even potential schedule slippage." These results, as stated, have in the past and unfortunaetly, Without accurate estimates and forececasts could plague future programs.

SHIPBUILDING SUPPORTING INDUSTRIAL BASE

The industrial base that manufactures key systems, components and material is comprised of approximately 1300 US and Canadian companies. This base consists of a cross-section of major corporations, small business concerns, sole proprietorships, partnerships, government-owned, government-operated and government-owned, contractor-operated facilities. Complementing this base is a network of support companies including distributors, design agents, service companies, assembly plants and subcomponent manufacturers. The major manufacturers under contract to government and shipbuilders are dispersed throughout the country. Large smokestack industries continue to be concentrated in the Northeast and Midwest, whereas the combat systems base is located predominately in California and the Northeast. Canadian manufacturers of major components and systems are located mostly in the Eastern part of the nation. Primary products manufactured by this North American Industrial Base includes; reduction gears, shafting, steam and diesel engines, gas turbines, combat systems/components, ordnance, communication and electrical equipment.

Although many HM&E industries can be considered "healthy", capacity reductions and MLT increases are occurring in some key Navy supportive segments. The segment of the base that manufactures propulsion diesel engines and gas and steam turbine engines has been reduced by approximately 40% since 1980. There are currently only two active producers of steam turbines, one of which, has recently conslidated and moved its manufacturing site. There is only one manufacturer of gas turbines and one of large diesel engines and they and do not manufacturre slow speed engines frequently used **in new commercial** ships.MLTS for diesel **engines have** increased slightly since l987. There were eight reduction gear manufacturers producing reduction gears for large naval applications in 1980. Today, five are suppoting Navy programs and only three have in grinding capability to produce state-of-the art hardened and ground reduction gears. since 1988, MLTs have increased from 15 to 19 moths. The depressed condition of the **gear industry is of such significance to the Navy that procurement of some Navy reduction** gears has been restricted to us manufacturer.

manufacturers of propulsion shafting for large applications has been reduced from five firms to three since 1980, with one inactive in **Navy programs at present. MLTs for this industry have increased from six to eight months. Since FEB 86, DOD has restricted procurement of all ship shafting, except that used on service and landing craft, to US or**

Canadian sources.

Large marine propeller manufacturers in the US has declined from seven to five since 1980, while MLTs increased from nine months in 1985 to 14 months forecasted for 1990.

Many other Navy supportive industries have realized capacity reductions and MLT increases since 1980. They represent a cross section of nearly every industry including; bearings, motors, generators, switchboards, pipe and tubing, compressors, steel plate, castings, deck equipment and cable.

Considering past industry trends, the lack of US commercial ship construction the probabilty that future Navy ship work will decline, and difficulty domestic manufacturere have experienced in their attempts to become competitive on the international market, continued loss of capacity and MLT increases many key industries is expected throughout the foreseeable future. continued erosion of the u s - Base will result in increases of single and sole sourcing loss or transfer of production capacity to foreign sources, causing a significant reduction in domestic productive capacity.

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24.1990

Shipyard Modelling-Approach to Obtain Comprehensive Understanding of Functions and Activities

1B-1

Joachim Brodda, BREMER VULKAN AG and Bremen Institute of Industrial Technology (BIBA)

NOMENCLATURE

CAD	Computer Aided Design
	Computer Aided Manufacturing
CASE	Computer Aided Planning
	Computer Aided Software Engineering
CIM	Computer Integrated Manufacturing
CNC	Computer Numerical Control
DNC	Direct Numerical Control
	Entity Relationsship Approach
ESPRIT	European Strategic Programme for Research and Development Information Technology
GRAI	Groupe de Recherche en Automatisation Integriel
ICAM	Integrated Computer Aided Manufacturing
IDEF	ICAM Definition
	Information Technology
NIAM	Nijssen Information Analysis Method
NIDDESC	Navy/Industry Digital Data Exchange Specification Committee
PDES	Product Data Exchange Specification
R + D	Research and Development
STEP	Standard for the Exchange of Product Model Data

ABSTRACT

The application of Computer Integrated Manufacure (CIM) to one-of-a-kind heavy engineering industries is one of today's most challenging tasks for the industry and Information Technology (IT) vendors. Because of the complextity of the shipbuilding process, as a typical representative of this kind of Industry, available solutions are not yet satisfactory. Even the basic theory of current CIM sytems does not fit many aspects of requirements for the shipbuilding industry. The application of CIM tools, which are based on ideas of line production and have a strict sequence of all tasks, have very often failed in the past, mainly because of a lack of flexibility. Therefore, basic work needs to be performed, starting with a detailed analysis of today's situation and leading to a careful development for the real re requirements of tomorrow. This paper deals with the problems resulting from the exceptitonal nature of shipbuilding for the application of CIM elements. The approach chosen for modelling of the production process, illustrated by some examples from actual Reseaarch and Development (R+D) projects, is described. An evaluation of the benefit of structured shipyard modelling and a look at complementary R+ D actions concludes the paper.

INTRODUCTION

Heavy industries, concerned with "one-of-a-kind". production, are typically described through combined workshop manufacturing and remote construction site assembly, and have not yet fully benefited in the application and use of modem information technologres.

The design and manufacturing of large multi systems intergrating products (ships, offishore structures, plane, factories) is a complex and long term activity covering a whole range of possible engineering and working activities. The manufacturing, process can be subdivided mainly into three parts: fabrication using standard and non-standard raw materials; the prefabrication of modules, including pre -assembly with other prefabricated or purchased products; and the final outfitting activities. P this complex manufacturing process, all production activities can normally be found at one production site.

The manufacturing process is construction site oriented with its signification cant amounts of specialized workshop production. The ical overlapping of design, planning and manufacturing means that, compared to mass production with line character, there has been a delay in the development of tools for these more complex requirements.

To come to a CIM solution in this kind of industry, a lot of additional basic work is required which can nevertheless be set up based on common standardization of definitions and rules.

Over the past ten years the shipbuilding industry has not been slow in adapting the latest Computer Aided Desing (CAD) techniques. Similarly, although the use of numerically controlled (NC) equipment,, e.g. for flame cutting, is commonplace. In this context there is already some computerized intergration of CAD and Computer Aided Manufacturing (CAM). Some links are also existing between CAD and Computer Aided Planning (CAP) and Production Planning and Control (PPC) Systems through the generation and completion of bills of materials.

However, the majority of systems in use are mostly 'island' solutions which are supporting work in special application fields. Below the level of PPC-Systems the information flow is mainly paper based, or on a person-to-person level.

Before starting into the development of ideas for CIM applications, the need for a detailed analysis of the resent situation of one-of-a-kind production in genera and shipbuilding in particular is evident. The analysis should cover different viewpoints of the process, such as manufacturing functions, process planning and control functions, organizational aspects, resources and information links. The use of formalised modelling methods even for analysis purposes provides a good basis for the development of requirement for the future system, i.e. an architectural reference model. This model defines the complete set of fnnctionalities, single activities and interrelations required for the production process. CIM elements and in particular also the remaining manual tasks as intergrated elements can be identified or defined on the basis of this reference model.

Organizational changes, the 'development of CIM elements, and the specification of interfaces as main element can be prepared. Any changes with respect to the today's situation can be documented.

Models based on common descriptive languages therefore provide a good opportunity for the discussion between system users and system developers. The more complex the task, and the less clear activity sequences are, the more important the use of formalised modelling techniques is. The original shipbuilding process combined with its manifold external dependencies represents a challenging production process to be described.

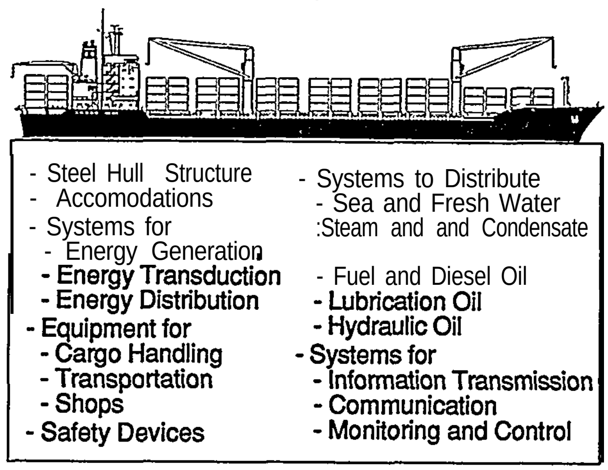
THE CHARACTER OF SHIPBUILDING

The shipbuilding process has been chosen for a number of principal actions within European R + D. As reference products of one-of-a-kind manufacturing ships provide good opportunities for basic investigations. Compared with mass production, significant differences can be identified as:

- tremendous influence on design and manufacturing by the customers;
- complex complicated and multi-stage production process with high interdependencies;
- combined manufacturing principles at one site;
- use of universal equipment;
- craft skills are of vital importance for the assembly process;
- long term order throughput;
- character of products under contract changes;
- significant overlapping of design, planning and manufacturing;
- hostile working environments;
- final product definition only after contract signing possible;
- decisions with high relevance must be taken on basis of uncertain, stochastic information;
- product value is very high;
- order throughput times are very long;
- product size in volume and weight is very high.

In spite of being incomplete, this list gives some major reasons for the difficulties the utilization of advanced information technologies for shipbuilding which are originally designed for mass production.

Some of the points will be illustrated in the following.



'Figure 1: Ships-Multi Systems Products [10]

Ships, as unique and ambitious technical objects, contain numerous and different technical systems (Figure 1). These different systems require a related number of various skills and manufacturing principles. Different types of ships require different loads in typical work trades which can lead to considerably divergent loads. Figure 2 shows an example of the loads for four typical shi types. Depending on the type of shipyard - with high or low level of self-fabrication of parts and components - this also effects the collaboration with subcontracters or suppliers. Even case of specialization of a few ship types the flexibility of work trades and equipment must be kept. Therefore all facilities of the shipyard have to be designed for the widest range of products allowing nearly the same level of productivity and quality for the different production cases. In this context it is understandable that for shipbuilding all activities working towards an optimisation and integration of designing, planning, manufacturing, and assembly are of vital interest. Especially, methods and tools for plating, monitoring and control of the uncertain process must be a matter of special consideration.

During the preparation of offers for customers the design of the must be able to provide information of high accuracy for the calculation of required material, needed resources, different loads of

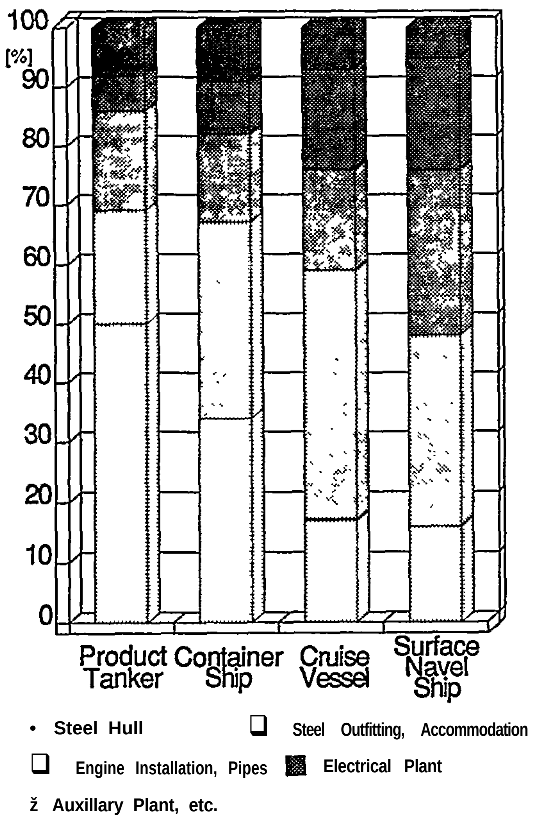


Figure 2: Different Ship Types Workload Distribution or Main Work Trades [10]

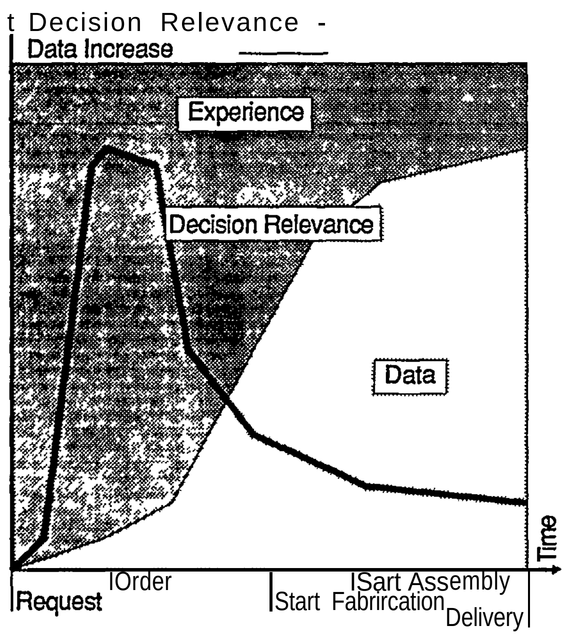


Figure 3: Decision Relevance Compared with Data

worktrades and time schedules. In this early stage of a potential order, decisions have to be made on the basis of forecasted figures which are of importance for the whole order throughput time. The preliminary design, without any detailed definition of the product, provides the more or less uncertain basis for those forecasts and decisions. The success or failure of an order for a company therefore depends highly on the skill and knowledge of the decision-making people who compensate for the lack of information in this early stage of a customers request with their experience.

Not only in this initial phase must missing data be compensated for by experience, but even in the m the production phase, mainly in the assembly process, workers make decisions about construction and design solutions, e.g. the routing of pipes. Therefore, ship, or compareable objects in size and complexity, do not necessarily need a 100% description by data. As long as a certain level of experience can be held at shipyards, the maximum level of data can be limited. Nevertheless, today's situation does not seem satisfactory. There ore, one of the tasks to be performe d is to find out the suitable level of data to be produced by advanced information technologies and the maximum gap to be levelled through human experience in the different stages of the order throughput. Figure 3 illustrates this coherence.

A reason for the need to balance the lack of data through experience can be seen in the significant overlapping of the different order throughput phases. Frgure 4 shows this overlapping compared with the situation in mass or series production. Because some

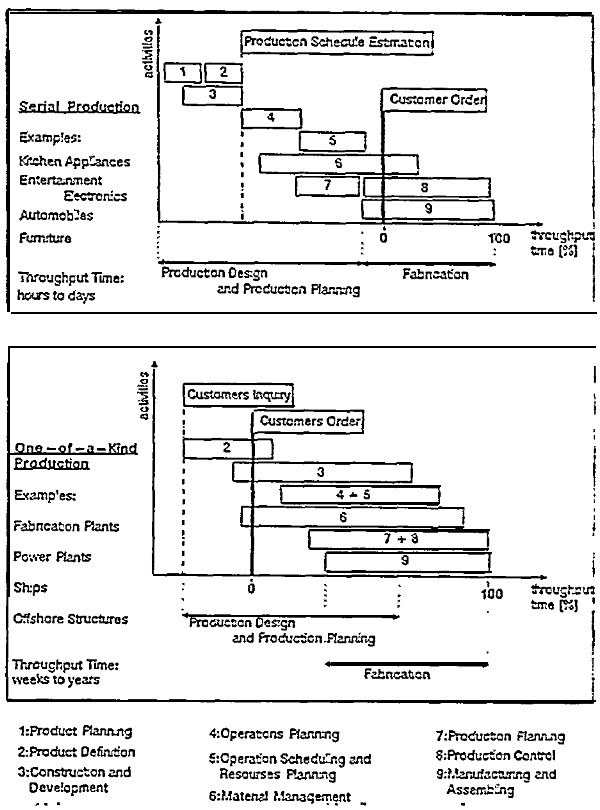


Figure 4: Different Overlapping of Main Activities for Serial Production and One-of-a-Rind Production

activites have to start before the required data has been produced, the 'realtime' generation of working instructions such as 'what to do' and 'how to do it' is required. Those working instructions very often are produced by the shop floor responsible without consulting the design office and higher level planning instances. The trust in the self responsibility and experience of these people by the company must be high. In spite of the danger this system naturally contains, advanced organizational principles, highly supported by modem information technologies, should carefully consider this flexibility of today's system as an asset of today, as well for tomorrow. Therefore a future (CIM) system must consider even the human role as an eminent element of the process.

The initial phase of the contract, i.e. the preliminary design, bases all calculations on the functional structure of the ship. The product will be designed from the system point of view. Constructional groupings (e.g. ballast water **system)** normally are approved structures of the product traditionally grown or tailor made for particular shipyards. This functional view of the system "ship" provides a good structure for different tasks in design and pre-calculations (functional structure). Because of the separate consideration of all constructional groups, resources, loods bend possible due dates, for this potential order calculated on this basis and preliminarily mapped into plans, cost centers and financial planing (cost/ quantity structure). Based on manufacturing capabilities' and and constraints (e.g. lifting capacities, space) the ship will be divided into manufacturing units(manufacturing structure) which provides the backbone for the bills of material for structure and further scheduling purposes (Figure 5).

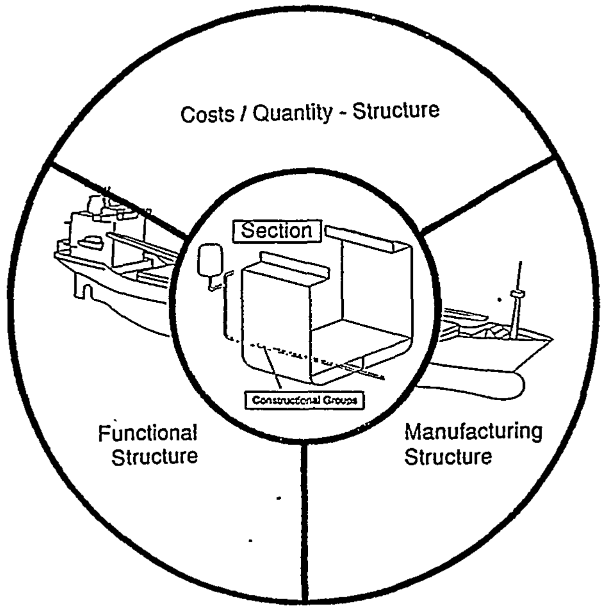


Figure 5: Threefold view on the Product Ship [BIBa]

Modem ship production techniques, like building big blocks with high quantities of pre-outfitting before assembling the ship within drydocks, defintely need a suitable manufacturing structure. With

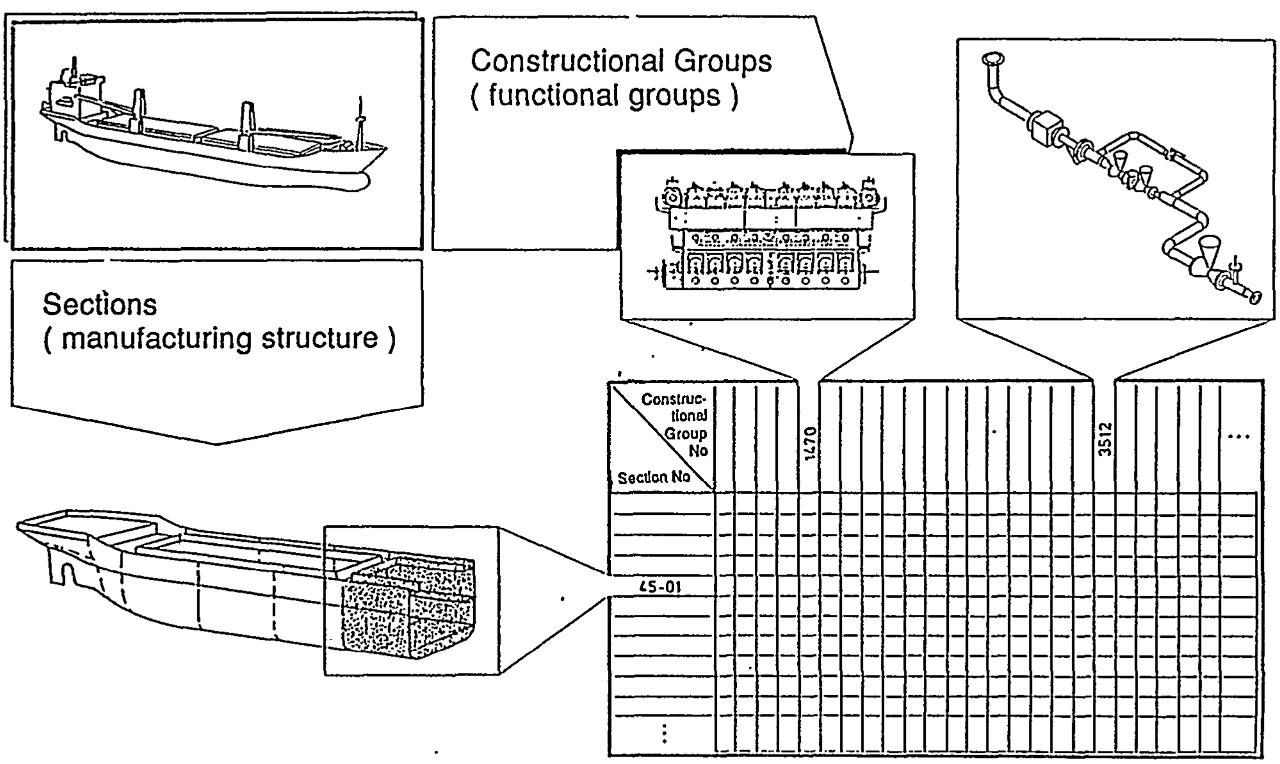


Figure 6: Integration of Manufacturing Structure and Functional Structure [BIBA]

the ongoing subdivision of the ship body the functional groups must be subdivided subdivided and distributed to related blocks and sections (Figure 6). This means the related bills of material, job cards and other planning documents must be merged in a suitable way which creates difficulties for conventional planning methods and tools.

The intention to extend the level of preoutfitting and to reduce the time spent at the final building place by the object makes it more important to think about the right structures and their interlinkages.

The different stages of the shipbuilding process can be subdivided into 7 levels (Figure 7). An additional stage for section or unit conservation should be considered between levels 3/4 or 4/.5. Because of the growing size and weight of the different objects between levels 2/3 there is usually a point during steel assembly where a transition is necessary from "moving product to process" to "moving process to product". Therefore levels 0, 1 and 2 can be performed following workshop production principles. On the other hand, levels 3 to 6 are mainly performed at construction sites. Figure 8 defines the different manufacturing principles. The three main parts of the production system - the working object, the worker and the production equipment - are defined as fixed or movable. In case of construction site manufacturing, the working object is fixed, at least for a certain time. All equipment and workers have to be moved to it. The main shipbuilding processes can be easily identified as belonging to this kind of manufacturing principle. Different pre-fabrication processes for steel and outfitting trades (e.g. pipes, sheet metal, accomodation) can be identified as workshop or even line production oriented processes (Figure 9).

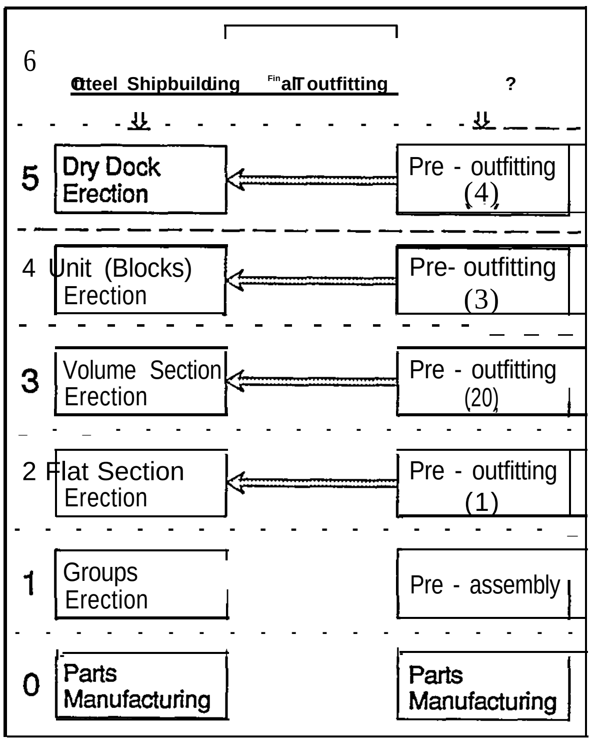


Figure 7: Levels of the Shipbuilding Process

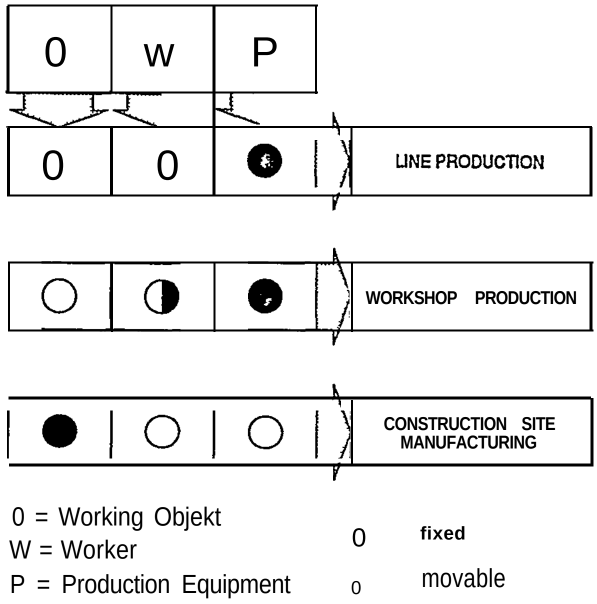


Figure 8: Definition of Manufacturing Principles

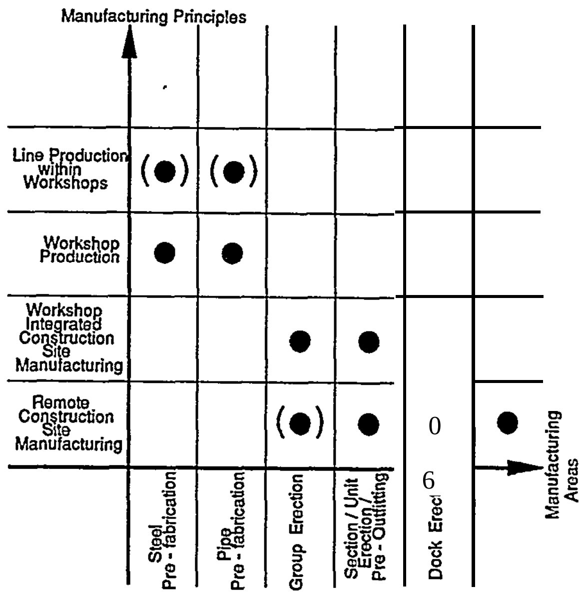


Figure 9: Assignment of Manufacturing Areas to Manufacturing Principles

These workshop or line production oriented tasks accompany the erection/construction site oriented processes throughout the whole construction time. Advanced shipyard concepts try to group those workshops closely around the related outfitting locations. For instance, Bremer Vulkan AG implemented the so called Workshop Oriented Ship Production Technology (WOST) concept which led to significant short cuts and reductions in outfitting costs. The idea was to minimize information links from workshop to the construction site by bringing outfitting intensive blocks under roof, close to the workshops.

This concept was realized for the engine room section and the superstructure. The highly pre-outfitted blocks then can be transferred to the dry dock by a gantry crane. After integrating the blocks into the hull as a final step of ship erection, the ship can be launched immediately.

Nevertheless some major tasks remain on remote construction sites. Because of hostile evironments, uncertain planning basis, unforeseeable changes through late delivery of material or weather influences, the monitoring and control of the production process is relatively difficult. Major reasons for these difficulties can be seen in communication problems of central planning instances with remote working people.

However the described character of the shipbuilding process shows some differences to other industry's. At least it provides some reasons for the need of some exceptional requirements and the need for adapted CIM theories and tools which are not yet satisfactorily provided by scientists and vendors.

MEANING OF CIM FOR SHIPYARDS

The integration of computers into the physical manufacturing process and all related management functions. for heay engineering industries in general and for shipbuilding in particular , is a very challenging task. First the question must be answered what computer integration means for this type of industry. It should be considered that 80% of the working hours or even more today are manual assembly tasks which can't be controlled by NC devices. This number will not significantly change within the near future. Therefore the industry highly de ends on the skill, the self-responsibilty and the flexibility of its working personnel on the shop floor. Many naturally existing deficits in craft manufacturing can be solved through improvements in organization, facilitating, and better support for the handling of material and layout improvements.

Naturally all possibilities for manufacturing automation should be considered. Solutions for the fabrication, e.g. of steel parts, are commonplace. For low level assembly tasks, mainly in the field of welding of subassemblies, some promising tools are available. Nevertheless investments in these tools comprise some difficult calculable risks and require corporate decisions. Beyond the question of how it is useful to mechanize or automate physical manufacturing processes, the generation and use of information for technical and management purposes must be carefully investigated. A process which depends highly on decisions made by experience needs improvements in information provision. Developments in this field are major objectrves of CIM approaches for shipbuilding.

CIM approaches should always be seen as an overall company strategy, giving more answers for "Integration" than just for "Computers" and "Manufacturing". In this context, the definition of clear corporate strategic targets for CIM is a must for every single company. Functions and activities of the manufacturing process have to be considered as having very close and manifold links to all other necessary tasks. This is particularly important to solve the integration aspect of CIM. However, it is essential for CIM to cover the whole range of company manufacturing activities. Partly implemented 'island solutions' or small groups of integrated systems might have improved the productivity of single company departments. However, the benefits of an overall integration are greater than those from the sum of 'island solutions'.

The one-of-a-kind nature of the product (ships), including the related special demands for manufacturing process and management, lead to some extended and exceptionel requirements for CIM. Because of individual differences between companies and a relativiely small market for IT vendors, combined with complex function for suitable software elements, many of these requirements couldn't be satisfied in the past. The man-machine interfaces are an es ecially imortant factor in the existing craft skilled 8dominated industry and will remain so in the future.

Thinking about movements towards CIM or even Computer Integrated Enterprise (CIE) the following field seems to be important in the future.

1. Consequent use of 3D-CAD-systems with complete substitution of physical engineroom models.
2. CAM systems with complex links to CAD for NC path generation and simulation e.g. Computer Numerical Controlled CNC) or Direct Numerical Controlled (DNC) weldingrobots for first to third stage assembly).
3. Integrated Computer Aided Engineering (CAE) and CAD systems allowing stage wise operations planning (for calculation purposes and manufacturing planning).
4. PPC combined with decentralised worktrade oriented control centers to serve three different levels of planning accuracy.
5. Object oriented production progress devices using user friendly data capturing
6. Communication technology for external links and internal fixed, temporary and movable requirements.
7. Neutral data base datastructure, and data base management concepts for product data, factory data and process data.
8. New concepts for data presentation to people in the yard (e.g. in the field of progress monitoring).
9. Knowledge Based Systems (KBS) especially for rescheduling purposes.

The hope for develo ments and improement in all these different IT fields are natural y based on open systems and neutral data storage concepts. In particular, shipbuilding and similar heavy engineering industries will definitely benefit from these approaches. It is doubtful whether individual, temporary or 'closed solutions can ever be gained from one-off product manufacturing.

THE NEED FOR MODELLING

To ensure that all single applications will fit into the whole CIM infrastructure in the shipyard, an overall CIM strategy must be found. Understanding the enterprise is essential before the future architectures can be developed. Existing system strutures have to be modelled in a compact and comprehensive form. Because of the natural interest to use general approaches it is necessary to think strategically and in long terms. Conventional, manual and intuitive approaches of today are not satisfactory in this context. Especially, the coordination of physical processes with information systems regarding hierarchical communication often exceed human imagination because of their complexity. Therefore, formalized techniques should be applied to analyse existing enterprize functions, information/data structures, organization and resources. The development of new structures leading to a reference model or future CIM applications should be based on the same techniques utilizing existing elements of the original structure. This approach provides a common language for the participating architects, users, experts, non-experts and iT developers from the beginning, and throughout the whole develo ment period. The model also provides a good basis or testing, simulation and cost-benefit-analysis of intended changes compared with the existing system.

The performance of methods and tools to be utilized should further allow mapping the processes globally and on detailed levels. At least the definition, specification and design of soft- and hardware should be supported. A three level approach to come to an implementation specification (Figure 10) follows in principle the particular derivation process of ESPRIT, project 688. ESPRIT is the "European Strategic Programme for Research and Development in Information Technology." The objective of this project was to design an Open System Architecture (OSA) for CIM and to define a set of concepts and rules to facilitate the building of future CIM systems.

The (future) reference model should be defined through careful analysis with transformation of the as is situation combined transformation and development into an ideal 'should be' scenario. The comparison with possible and available organizational and IT solutions lead, at least through intermediate stages, to an integrated implementation specification. The reference model updated through the implementations taken provides a basis for continued research and definition of an advanced CIM design.

MODELLING APPROACH

Several methods and tools for the different enterprise modelling tasks have been developed in the past. Those tools are often based on Computer Aided Software Engineering (CASE) tools and are utilized for the different modelling tasks. Because of the requirements of shipbuilding, including lots of decisions based on experience, and because of the special interest in the planning and control sector, the EsPRIT Project No. 2439 ROCOCO (Real Time Monitoring and control of construction Site Manufacturing) decided to follow the GRAI (Grou de Recherche en Automatisation Integriel) approach for modelling and methods. The ROCOCO project is lead by Bremer Vulkan AG and involves 4 more major

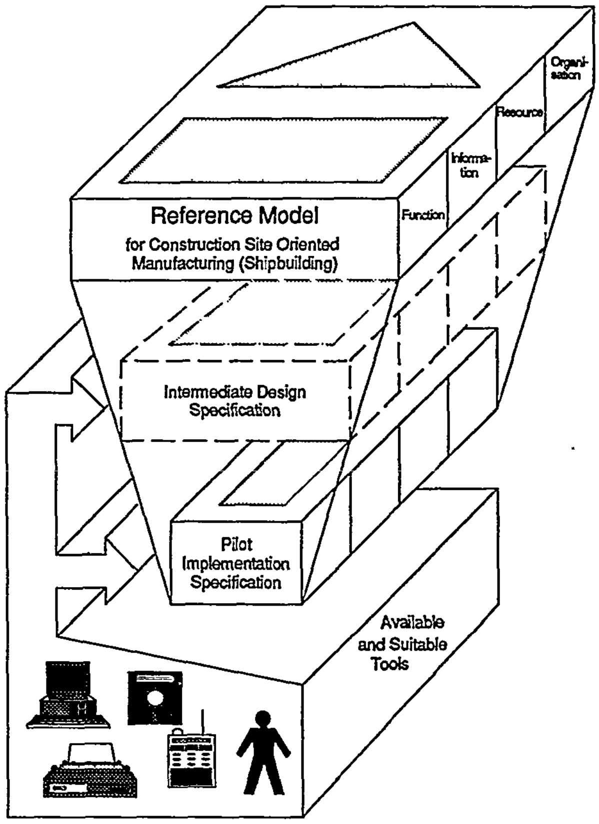


Figure 10: Three Level Approach for Factory Modelling

European shipyards (Chantiers de L'Atlantique, Fincantieri, Eleusis Shipyard, Masa Yards). At least 11 partners from Europe comprising research institutes, universities and IT vendors beneath the shipyards are forming the consortium.

To provide the basis for the tool development tasks, and as a major part of the project, a reference archrtecture customized to the intended application area must be developed.

Following the GRAI a preach the structured reference model will be subdivided into three sub-sytems (Figure 11). The operational sub-system describes the physical manufacturing (and design) functions and has the role of transforming, raw materials (and design orders) into end-products (and technical data).

The decision sub-system, also called the production and design management sub-system aims, to control the operatronal sub-system in order or reach the economic targets while taking constraints into account (Figure 12). The information sub-system links the two previous sub-systems and aims to supply and memorize the information, restitute and process it. From the various applicable methods and approaches IDEF 0 (see next subchapter) has been choosen for the operation sub-system and GRAI for the decisional sub-system. For the informational sub-system an Entity Relationship Approach (ERA) has to be applied. The

decision for a particular tool for information modelling has not been finally taken. Tests with several tools (e.g. IDEF 1 or the Nijssen Information Analysis Method (NIAM)) in context with other projects are under way.

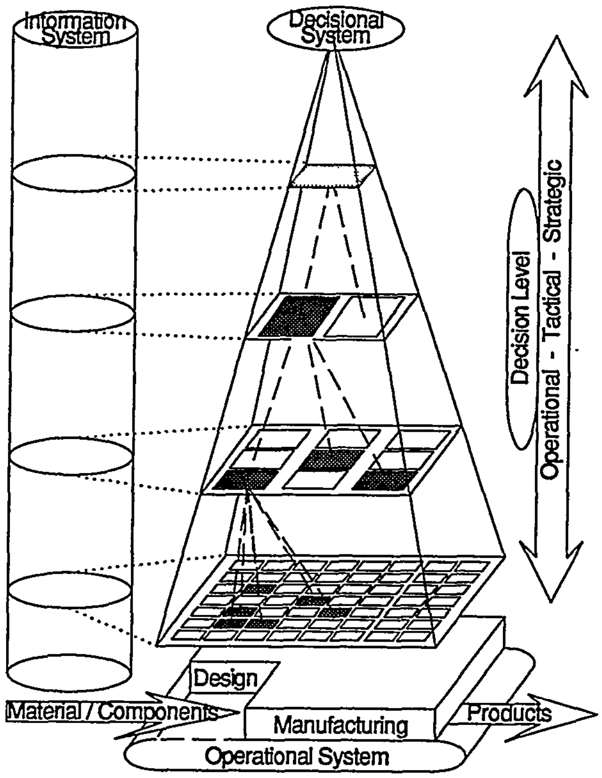


Figure 11: Reference Model-GRAI Approach [6]

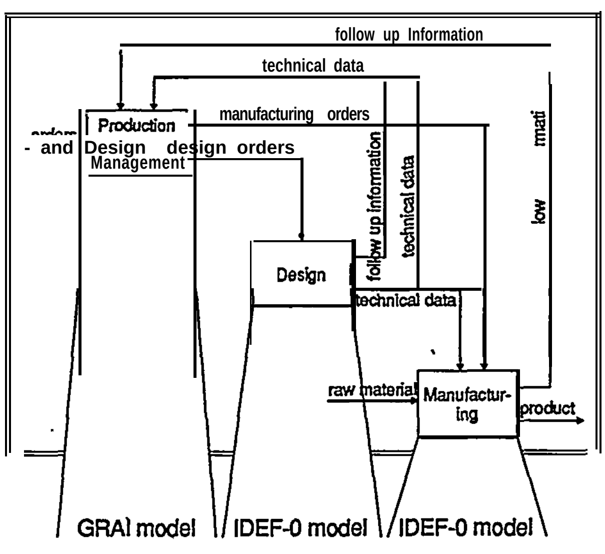


Figure 12: Assignment of Methods to Sub-Systems

IDEF Methodology

Originally the methodology has its roots in the US Air Force Program for Integrated Computer Aided Manufacturing (ICAM). This program identified the need for better communication and analysis between the people involved in improving manufacturing productivity. To satisfy that need the ICAM program developed the IDEF (ICAM DEFinition) methods to address particular characteristics of manufacturing.

The approach was to use the methods to produce models which would provide a basis for defining where changes to the manufacturing process would result in improvements to manufacturing productivity.

IDEF comprises three modelling methodologies which graphically characterize manufacturing. IDEF 0 is use to produce a “functional model”, which is a structured representation of the functions of a system and of the information and objects which interrelate those functions. IDEF 1 is used to produce an “information model” which represents the structure and semantics of information within the system. IDEF 2 is used to produce a “dynamic model” which represents the time varying behavioral characteristics of the system.

IDEF 0, which has been applied here,. consists of techniuse for performing system analysis and a graphical language for applying these techniques. The graphical language is limited to a set of basic components with which the analyst or designer can compose structures of any size. These basic components include boxes and arrows.

The IDEF 0 diagrams in a model are or organized in a hierarchical and modular “top-down” fashion showing the breakdown of the system into its component parts. Application of IDEF 0 starts with the most general or abstract description of the system to be produced. If this description is contained in a single ‘module,” represented by a box, that box is broken down into a number of more detailed boxes, each of which represents a component part. The component parts are then detailed, each on another diagram. Each part shown on a detail diagram is again broken down, and so forth, until the system is described to any desired level of detail. Lower level diagrams (children), then, are detailed breakdowns of higher level diagrams (parents). The place of each diagram in a model is indicated by a “node-number”, derived from the numbering of boxes. The boxes within the diagrams represent functions or activities in the hierarchy named by verbs connected by arrows representing the relationship (objects, information) labeled with nouns.

Figure 13 maps the application of the methodology for the ROCOCO project. Two different diagrams of the same level showing the same activity boxes describe first the material flow and second the information flow. This approach has been chosen for the ROCOCO project to keep the diagrams simpler. The lowest level diagrams are clear-cut single activities describing all inputs, outputs, controls and resources (material and information related). This gives a complete figure for these single activities and can be considered as kind of generic modelling elements forming the basis for the future definition of other models. A textual explanation diagram behind the original diagram gives the opportunity for additional comments.

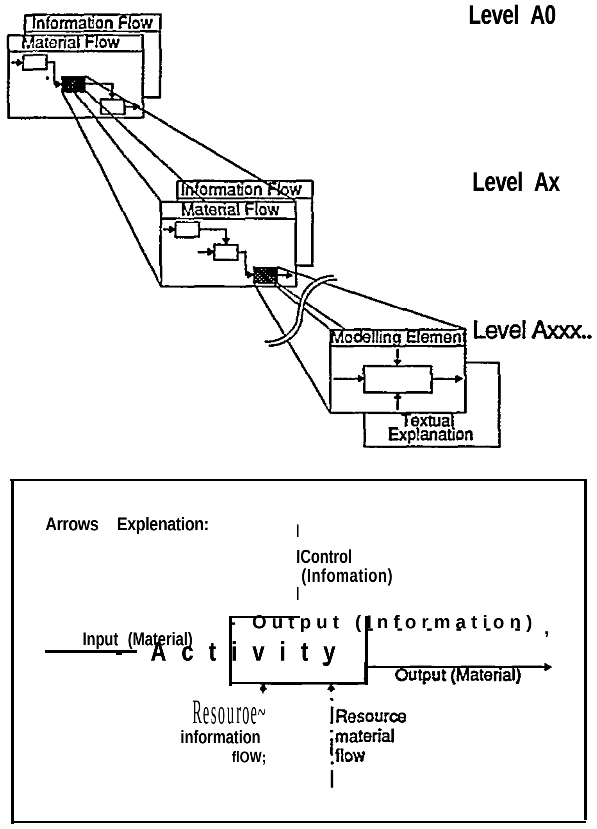


Figure 13: IDEF 0 - Structure Explanation [6]

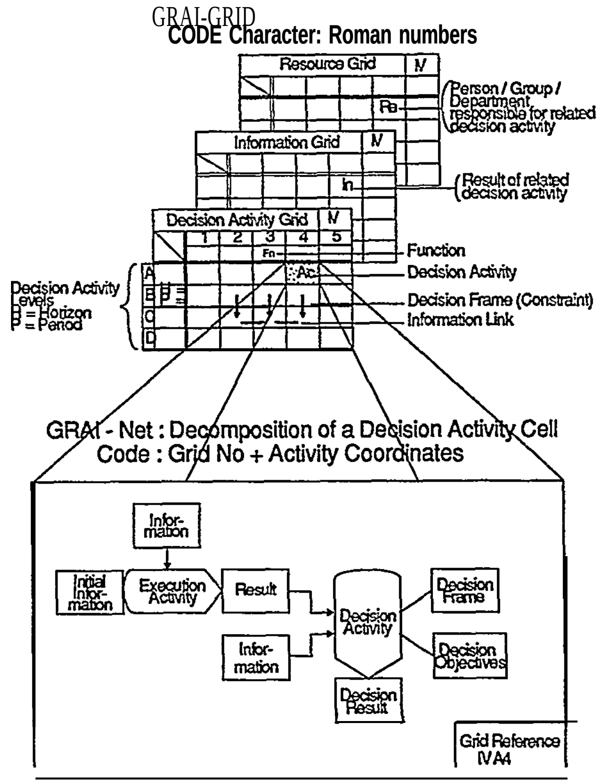


Figure 14: GRAI Method - Structure Explanation [V]

GRAI Methodology

The GRAI methodology has been developed by the GRAI Laboratory 0f Bordeaux University/France for the model considers processes. The GRAl conceptual considers a management (decisional) system as a hierarchical structure. This decisional system consists of decision activity centers as part of the company's management functions. Decision frames connect different decision activity centers of different levels. At least three main decision levels are common and the lowest level corresponds to the real time shop floor level. Besides the decision frames, information links ensure information exchanges between decision activity centers. These elements and concepts will be combined and realized in a "GRAI Decision Activity Grid." GRAI Grids give a hierarchical representation of the whole structure of decision activities in a Production Management System. In a matrix format functional criteria are used identify production management functions (columns). Decision time horizons combined with decision updating cycles criteria are used to identify decisional levels (rows). This leads to the definition of decision time horizons considered for the decision and a revision period (if any) as a time interval for decision verification. Decision activity centers as building blocks *of the Grid, are the intersections of the functional columns and the time dependent levels.

Full line arrows within the Grid represent decision links between different decision activity centers. In a working production management system a decision link leads always **from** a higher level to a lower level or it is used to connect two centers on the same level, but never from a lower level to a higher level. Broken line arrows represent information links connecting decision centers without restrictions.

After the most important Decision Activity Grid two more Grids can be defined. The intersections of functions and levels in the Information Grid contain the result of the related decision activity. The Resource Grid provides information on persons, groups, departments or tools responsible for the related decision activity. Therefore it also considers organizational aspects.

The decision activity centers of the GRAI Grid will be decomposed into so called GRAI Nets. GRAI Nets give a more detailed descrition of the various activities with the decision activity center. This description includes the interrelations with other decision activity centers. Additionally , because of the importance of decision activities, variables,. objectives, and rules can be identified and expressed.

Figures 14 and 15 give some more explanations on the GRAI methodology as used within the ROCOCO project. Within this context the following definitions should be considered:

decision frame	-	constraint for the following decision activity;
decision objective	-	aim to be achieved by the decision activity;
decision variables	-	variables allowed to be influenced by the decision activity;
decision rules	-	rules to be followed by the decision activity obligatory;
trigger	-	information triggering execution or decision activities;
request		information given on request;
information	-	information given automatically;
address		information address - where from/ where to.

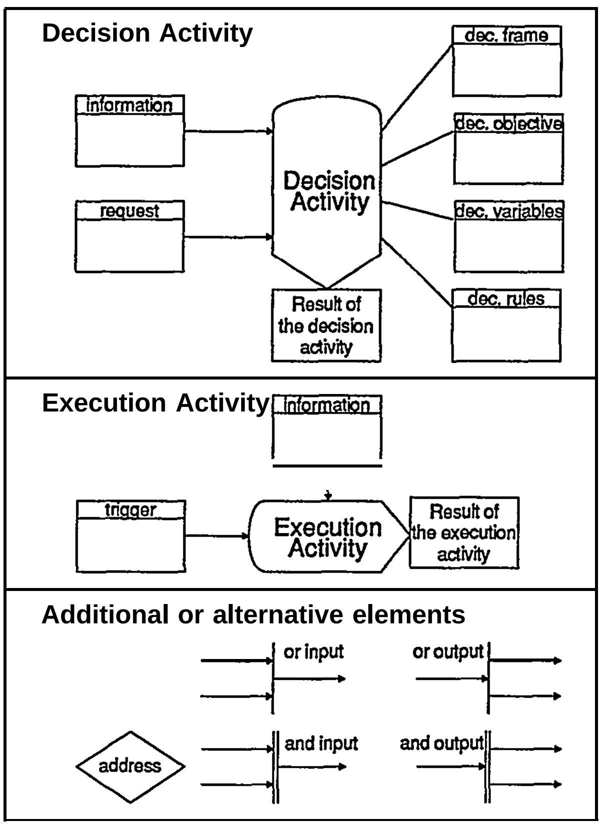


Figure 15: GRAI Method - Net Elements Explanation [6]

Integrated Methodology

The integration of IDEF 0 and GRAI methodologies follows basically the ideas of ESPRIT Project No. 418 “Open CAM Systems”. Even here operational sub-systems, namely the physical manufacturing functions, will be modelled by using the IDEF 0 methodology. The decisional sub-system of the model will be described by the GRAI approach. The principle connection of the two methods is shown in Figure 16. The control arrow is therefore directly or indirectly (via another IDEF 0 box) coming from the GRAI model. The follow up information to the following IDEF 0 box is described with an output arrow. The control and output arrows are labeld with addresses defining the IDEF 0 box/node number or the GRAI Net Reference number.

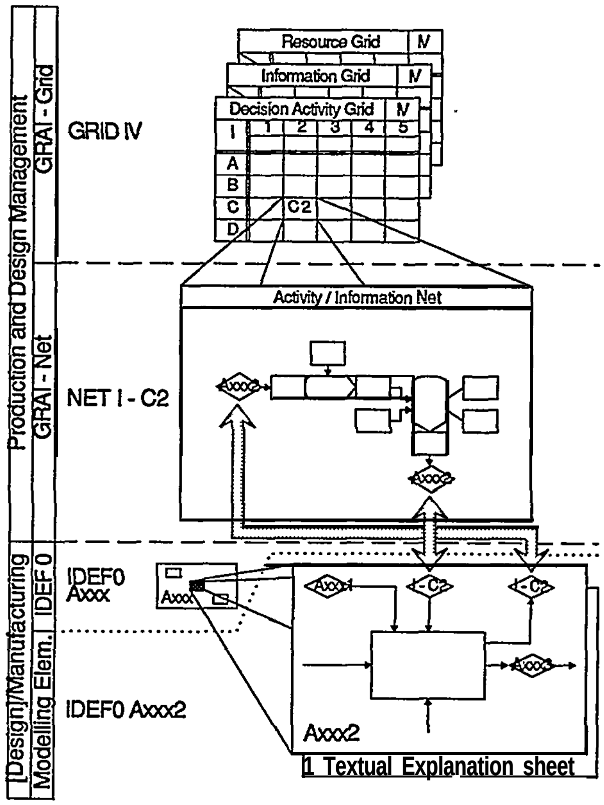


Figure 16: Linkage of GRAI and IDEF 0 [6]

MANAGEMENT FUNCTIONS MODELLING

The GRAI Grid, developed for one-of-a-kind production management systems, identifies 8 different levels with different management time horizons and periods (Figure 17). Levels A/B/C are for more strategic decisions, levels D/E/F have a more tactical character, and levels G/H should cover the operational tasks. In this context it 1s difficult to define clear figures for horizons and periods for shipbuilding characterized as an unstable production process with many unforeseeable events. Therefore the mentioned can be considered as typical figures, but are

Grid I - Centralized Activities

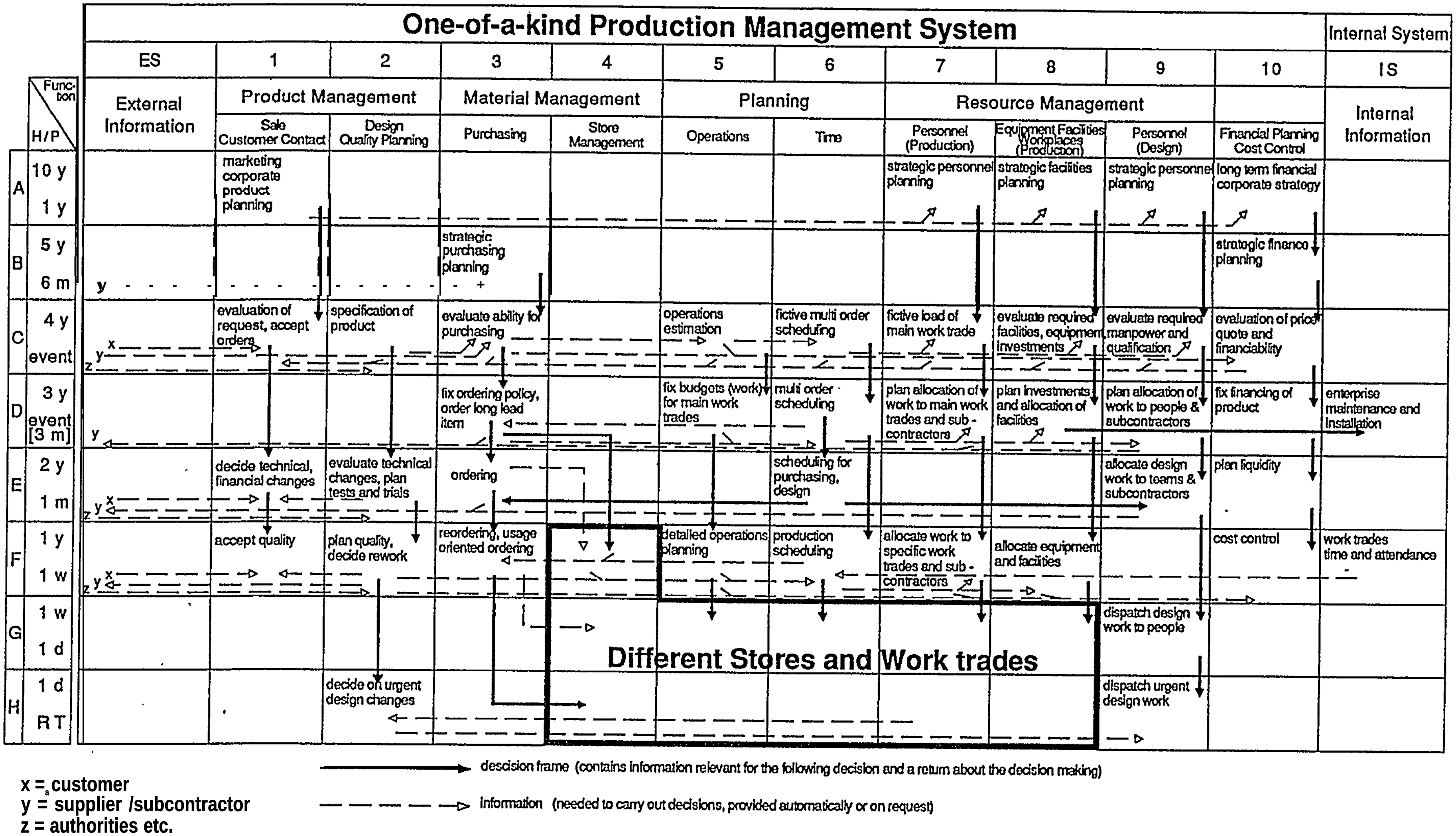


Figure 17: GRAI Grid Example [6]

Grid IV - Pipe Installation

Function / HIP		One-of-a-kind Production Management System										Internal Systemn
		Es	1	2	3	4	5	6	7	8	9	10	IS
		External Information	Product Management		Material Management		Planning		Resource Management				Internal Information
			sale Customer Contact	Quality Planning	Purchasing	Store Management	operations	Time	Personnel (Production)	Equipment Facilities Workplaces	Personnel	Financial Planning	
A	10 y / 1 y												
B	5 y / 6 m												
C	4 y / event												
D	3 y / event [3 m]												
E	2 y / 1 m												
F	1 y / 1 w					stock level control	operations planning	production scheduling	allocate to specific work trades and subcontractors	allocate equipment facilities and workplaces			
G	1 w / 1 d					daily balance of delivered material and extracted	complementary operations planning	detailed pipe installation scheduling	dispatch work to teamleaders and subcontractors	allocate workplaces			other work trades time and attendance
H	1 d / RT			decide on urgent design changes		incoming material inspection, prepare stock issue		detailed team scheduling	dispatch work to workers,	check workplace occupation			other work trades time and attendance

b descision frame (contains Information relevant for the following decision and a return about the decision making)

Information (needed to carry out decisions, provided automatically or on request)

x = customer
y = supplier I subcontractor
z = authorities etc.

Figure 18: GRAI Sub-Grid Example [6]

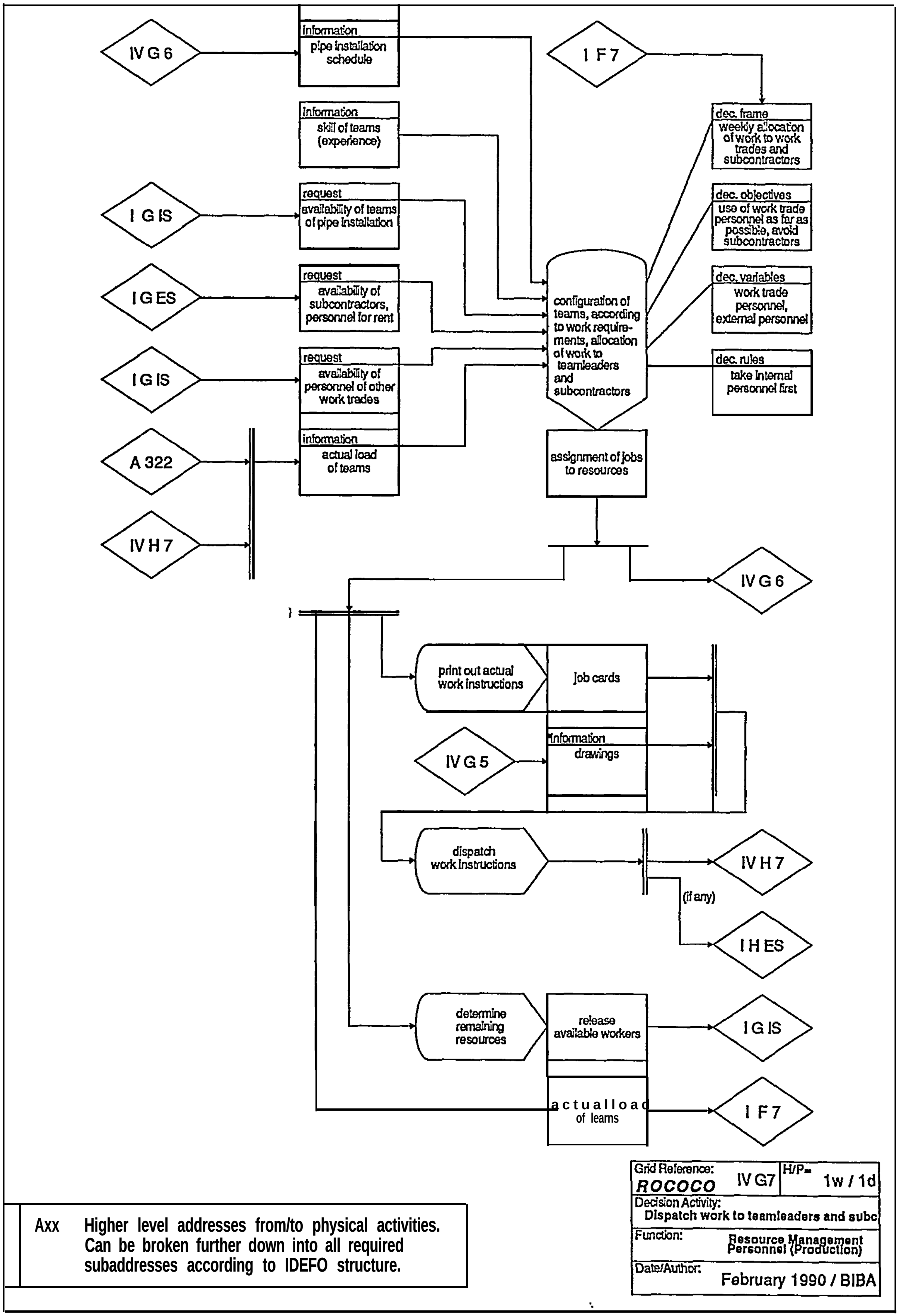


Figure 19: GRAI Net Example [6]

very often disturbed by events. The problem is smaller for the low level (operational) planning and resource management activities, i.e. 'nearer' to the physical process.

Four main functions have been considered further, broken down into at least 10 subfunctions (columns). Compared with grids developed for series production, the subfunctions 'customer contact,' 'design. management, 'operations planning,' and 'design personnel management' have to be considered in addition. Even under the other functions several activities have to be mentioned which are of less importance to other industries.

The heavily framed activities in the GRAI Grid are specific for different worktrades, and stores. The decision activity grid for the pipe installation management process (Figure 18), for example, can be overlaid. Combined with another grid for a specific store, a comprehensive grid for one special case occurs. The grid structure is completed through 'shadow' grids comprising the information generated by the activity and the resources responsible for the activity.

The grids should provide a good overview of the most important decision activities. For activity centers of special interest a further detailing through a GRAI Net is required. Figure 19 gives an example related to Grid IV (figure 18), activity coordinates G7. If required, a further break down of the specific decision or execution activity within this Net might be generated.

DESIGN AND MANUFACTURING FUNCTIONS MODELLING

The shipbuilding operational functions have been subdivided into five major subfunctions. Figure 20 shows a part of the IDEF 0 functions and activity breakdowns for outfitting sytems manufacturing functions. In particular the branch for pipe system related functions has been followed here. Further down, three different functions - running the pipe stockyard, fabricating pipe systems, installing pipe systems - are distinguished. The "pipe system installation" is shown broken down into two more detailed levels, allowing the smallest description of single clear-cut activities (modelling elements).

For the breakdown structure reference No. A 3232, 'To install fabricated pi es,' outlined IDEF 0 diagrams: one for material flow and another for information flow are shown in figure 21 and 22. For example, the presentation of clear- cut activity No. A 32322 is given in figure 23.

MODELLING BENEFITS

Beyond the general benefits already mentioned above under "The need for modelling," modelling actions produce some other positive side-effects for a CIM approach.

An expert team was chosen to represent the key-functions of the company and to describe their working-system from a top-down view throught the analysis phase. One effect of the ensuing discussions was to see the experts learning to recognize and to understand some problems of their colleagues. Because of the 'integration' aspect of the discussion for some of the experts, the consequences of omitted work with no local relevance became more apparent. This is very important for the generation of the future reference model from basically the same team. For the validation of the results proved d through the top-down approach, people in the related lower hierarchical positions, or those having decision responsibilities for single decision activities (GRAI structure), were asked for their view on the working-system. The effect of the involvement of all these people in an analysis and definition procedure is to obtain more acceptance of the approach itself and to limit distrust of future implementation.

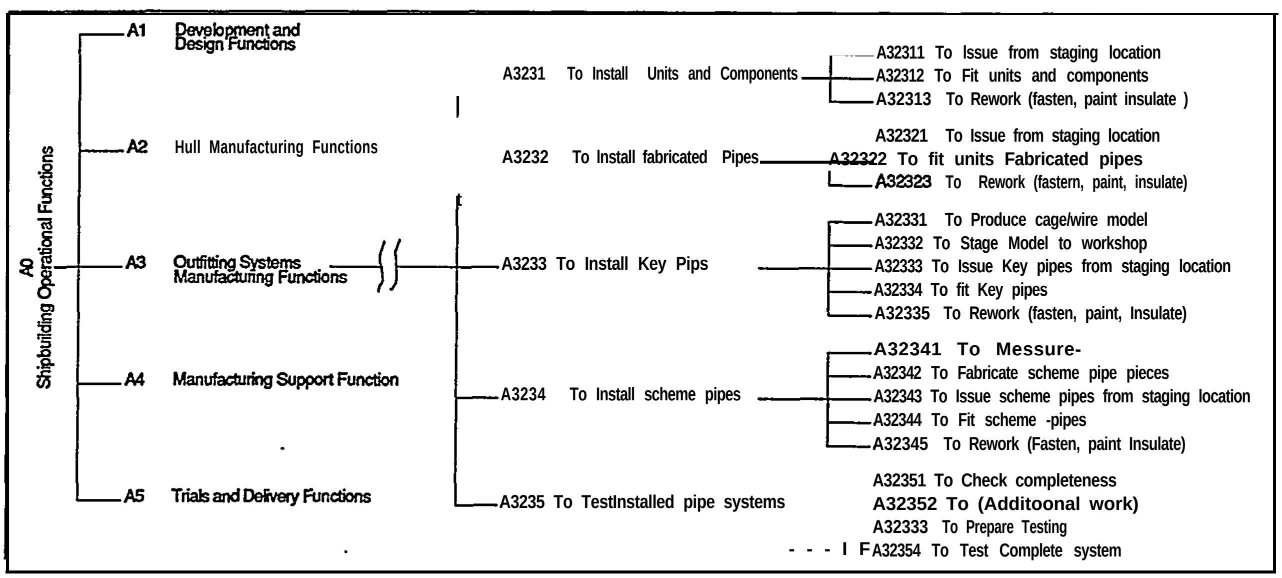


Figure 20: IDEF 0 - Subset of an Exemplary Function and Activity Breakdown Structure [6]

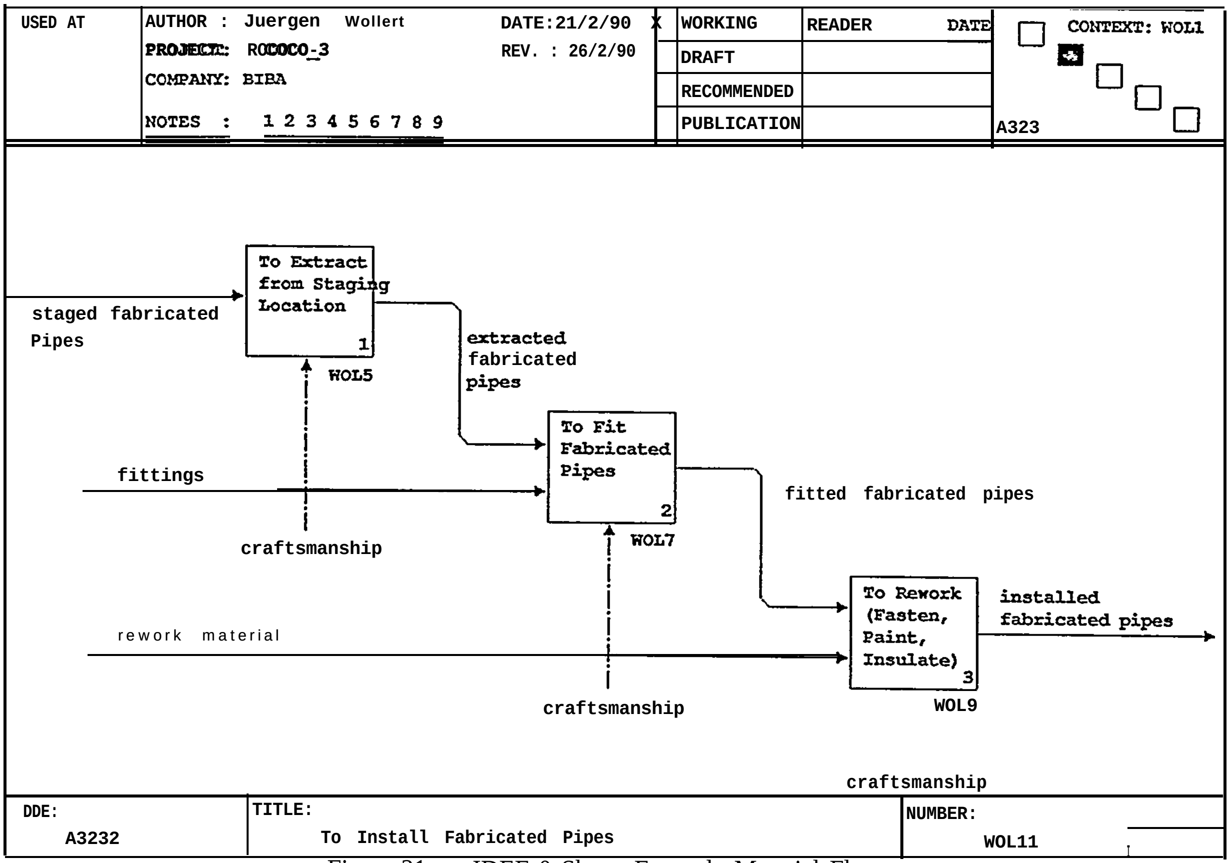


Figure 21: IDEF 0 Sheet; Example Material Flow

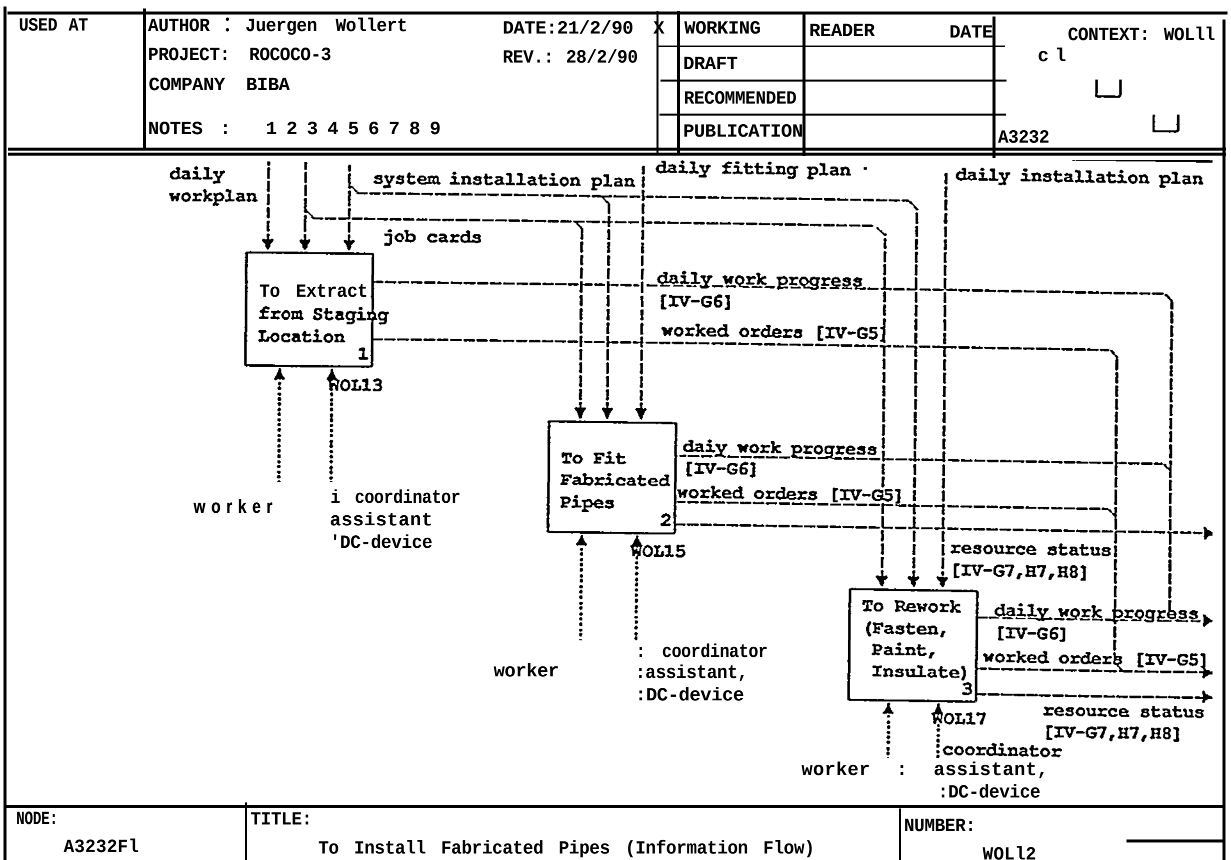


Figure 22: IDEF 0 Sheet; Example Information Flow

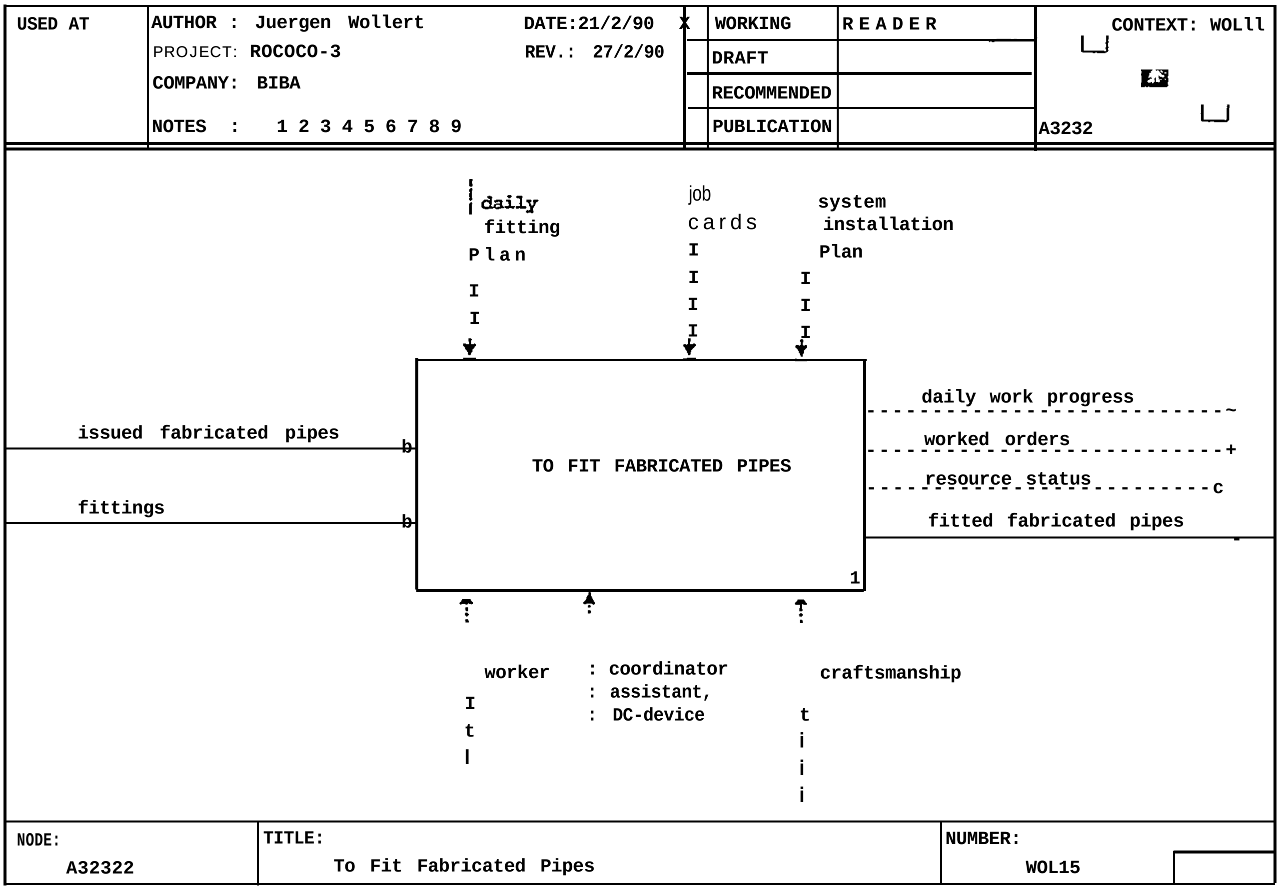


Figure 23: IDEF 0 Sheet; Example Modelling Element

These analysis should be considered by a company before using external consultant. The formulation of CIM for every single company must be found internally by the company's key personnel. External help should be limited to experts for the formal application of the method or for the development of solutions for specified questions. The initiative should always be taken by the problem owner - the company. Then, modelling approaches keep what they promise and offer their full benefits.

COMPLEMENTARY ACTIONS

The European shipbuilding industry is realizing, more and more, the challenge of CIM. Through the consideration of European R + D programs, the collaboration between major shipyards grows more permanent.

Considering CIM as a threefold problem of:

functionality of software (CAD, CAM, PPC etc.);

2. data storage (structure, accessability, data bases etc.); and

3. communication networks and communication (user) inter-faces;

lots of different projects have recently been launched.

These projects are too numerous to refer to individually. However, two representative projects dealing with modelling in a similar context should be mentioned.

<u>ESPRIT Project Nr. 2010 'NEUTRABAS</u>
(Neutral Product Definition Database for Large Multifunctional Sytems).

The objective of this project is to develop standardized methods for the storage and exchange of data defining shipbuilding and ocean engineering products. The work is based on standardized interface formats such as "Product Data Exchange Specification" (PDES) and "Standard for the Exchange of Product Model Data" (STEP) and will define the principles of application oriented reference models relating to complex maritime products.

It is also expected that the project will provide a valuable contribtuion to international standardization in the area of data exchange technologies. Contacts to other groups such as the Navy/Industry Digital Data Exchange Standards Committee (IDDESC) in the United States have been already established.

ESPRIT Projekt No. 3143 'FOF
(Factory of the Future Production Theory)

The project is dealing with the develop ment of new production philosophies and a designer's workbench for the development of CIM in production systems, especially for 'one-of-a-kind' products. The project is running under the framework of ESPRIT basic research actions. The consortium comprises 7 well established universities and research institutes. The group feels it necessary to look for alternative ideas to the theory of F.W. Taylor. The shortening of product lifecycles and the trend towards individual products makes it necessary to think about more suitable solutions for the future compared with those for mass production. After other effected products (planes planes, computers), ships play an exemplary role in this project.To understand the real differences in the manufacturing principles of the effected industry and compare these with series production (e.g. automotive industry), it is a goal of the project to model exemplary and comparable production activities utilizing the same methods.

The results, at least generally, promise some answers for principle questions and as well for the applicability of CIM within the shipbuilding industry.

CONCLUSIONS

The utilization of diverse modelling methods and tools to specify the system requirements of CIM for the shiproduction process facilitates understandin the manifold and complex interrelations. Method(s) chosen for a 'common language' to describe the 'as is' and the 'should be' situation are very necessary. As a language understandable for IT experts and matter-experts, modeling can bridge the traditional gap between vendors and users. The results are not Just temporary, but also useful for the documentation of the actual situation, for the evaluation and simulation of future concepts, or suitably computerized to manage the implemented CIM elements. This takes the whole modelling a approach to a new and useful dimension. The modeling work leads at least to a living, functional, and informational, organization and resource model for the company. Even though, the work IS just beginning, results are promising and already of / help.

Through the acceptance and motivation of the modelling team and through improvements in modelling techniques and tools, the modelling approach will definitely lead to benefits for the shipbuilding industry.

ACKNOWLEDGEMENTS

The author wish to express appreciation to all collegues of the ROCOCO project and the Bremen Institute of Industrial Technology (BIBA) for comments and contributions to thus paper. Special thanks go to Jurgen Wollert and Markus Lehne for their advice and to Sieglinde Precht without whose help this paper would not have been possible.

The conclusions and opinions expressed in this pa Paperer are the author's own, and do not necessarily reflect the opinion of any other source.

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Paper presented at the NSRP 1990 Ship Production Symposium, Pfister Hotel, Milwaukee. Wisconsin, August 21-24.1990

Managing the Environmental/Health/Safety Risks at a Major Shipyard

IB-2

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ABSTRACT

The complexity of shipyard operations, in combination with the diverse and numerous hazardous materials used in manufacturing and repair, present unique environmental, health and safety challenges. One shipyard has taken a proactive approach to hazard identification, assessment and control in order to effectively manage these risks. This included a major risk screening, consequence modeling of the scenarios developed and the generation of practical risk control options. Such action facilitated the development of a comprehensive, multi-disciplinary emergency response plan as well as compliance with regulations promulgated as the result of the Superfund Amendments and Reauthorization Act of 1986.

Introduction

The complexity of shipyard operations, in combination with the diverse and numerous hazardous materials used in manufacturing and repair, present unique environmental, health and safety challenges. Whether it be fabrication or repair or vessels with steel, fiberglass or wooden construction, there are inherent risks that may have the potential for significant on-site and off-site impact. For example, consider the drum storage of solvents, bulk propane stored in Lullets, cylinder storage of acetylene, or the tank storage of gasoline. While these installations are typical of shipyard operations, all present the potential for significant environmental/health/ safety risks when considering the consequences of major accidents. A proactive approach to hazard identification, assessment and control is recommended in order to effectively manage these and the other risks found in shipyards worldwide.

The Need for State-of-the-Art RISK Management

There is a well-defined need for state-of-the-art risk management at shipyards as evidenced by the risks inherent in their operations and new regulations pertaining to hazardous materials and emergency response. The latter includes The Superfund Amendments and Reauthorization Act of 1986 (SARA). Section 303 of this document presents the need for a facility response plan which addresses the risks and appropriate response measures for releases of extremely hazardous substances. In Section 126, the Occupational Safety and Health Administration (OSHA) was required to issue a standard which would protect those workers engaged in hazardous waste operations and emergency response. The regulations promulgated called for the development of a hazardous waste operations health and safety program and the development of an emergency response plan.

An approach to effective technological risk management can involve the following steps as presented in Figure 1:

Hazard Identification: the systematic identification of property, casualty, or liability hazards that may result from corporate operations and product use;

Risk Screening: the ranking or ordering of identified hazards according to their relative degree of risk, so that risk management resources can be invested where the need is the greatest;

Risk Estimation : for those risks deemed sufficiently important, the estimation of both the expected frequency of adverse events and the magnitude of losses that might result;

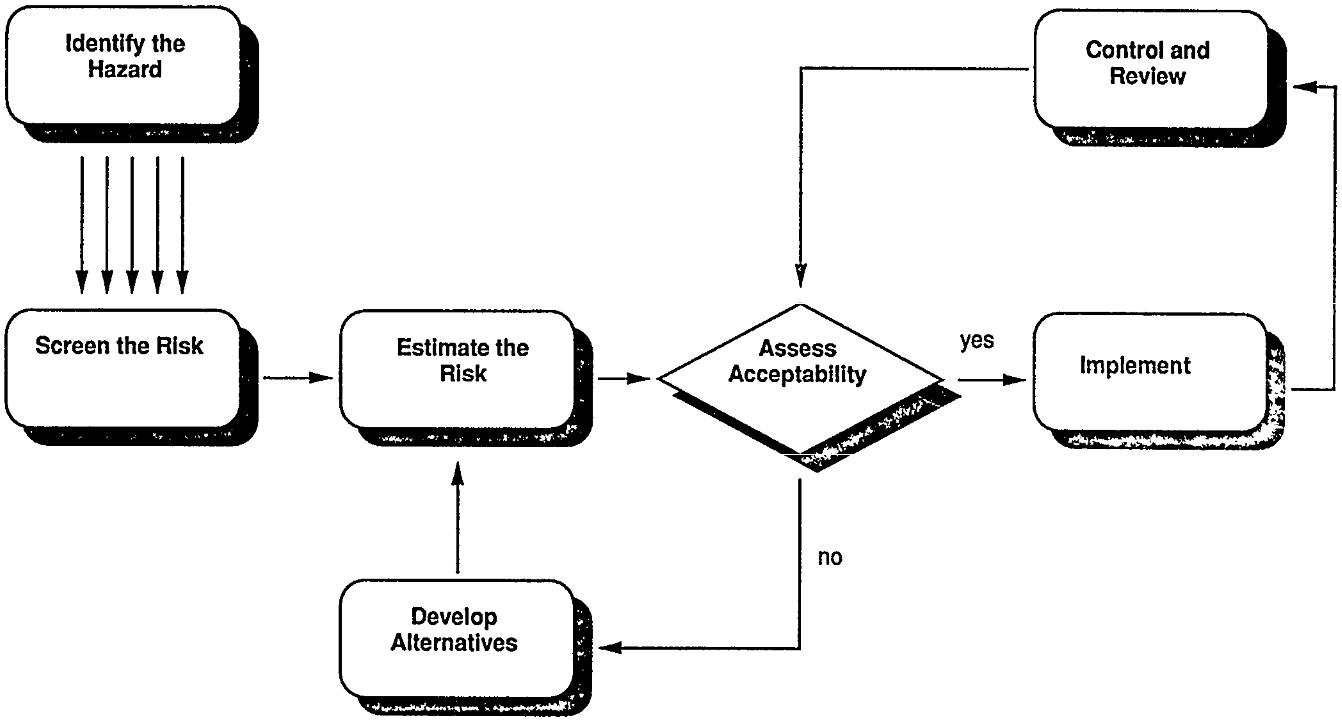

FIGURE 1
PROCESS FOR MANAGING
RISKS

Acceptability Assessment: the evaluation of risks that have been identified and estimated in the previous steps to determine whether these risks can be tolerated;

Development of Alternatives: the selection of cost-effective actions for reducing or mitigating unacceptable risks, including technological and management controls; and

Implementation, Control, and Review : implementation of necessary mitigation measures to control risk to acceptable levels and periodic monitoring and review of risks.

This approach can be adapted as a function of the shipyard or facility, its anticipated risks and a need to comply with specific regulations.

Hazard Identification and Risk Screening

Considering the need for shipyards to comply with the Superfund Amendments and Reauthorization Act of 1986 regulations, hazards must be identified and screened as a function of potential risk. This can be done in two separate but related efforts. The first involves the field application of process hazard, safety management and fire protection and emergency response protocols to develop a list of "most likely" and "worst case" release scenarios or events that would have potential for major impact on human life, and/or company assets. These scenarios can then be further examined to set the stage for appropriate emergency response measures for releases of extremely hazardous substances as mandated in Section 303.

The second, related effort in response to the Occupational Safety and Health Administration regulations involves hazardous waste site characterization with associated hazard identification and evaluation. After review of applicable site information, e.g., site plans, material safety data sheets. materials inventory, waste manifests, etc., established protocols can then be used when conducting a thorough inspection of hazardous waste operations. In addition to identifying and evaluating potential chemical, physical, biological and ergonomic hazards, this should also include an evaluation of safety inspection procedures, industrial hygiene monitoring, personal protective equipment programs, the Worker Right-to-Know program, employee training, medical surveillance, equipment safety programs and waste handling areas.

Consequence Modeling

Having identified a list of "most likely" and "worst case" scenarios, risk assessment efforts can then be conducted to better understand the magnitude of losses that might result. If one considers the potential risks associated with releases of propane, oxygen, acetylene, gasoline, ammonia, methyl-ethylketone and solvents, use of the following hazard assessment models is appropriate:

- thermal radiation hazards from pool fires;
- unsteady state thermal radiation hazards from a boiling liquid expanding vapor explosions (BLEVEs);
- flammable vapor dispersion hazards;
- toxic vapor dispersion hazards; and
- explosion overpressure hazards.

Use of these models results in the characterization of potential events and the estimation of the area or population affected by the release, assuming no mitigation. This is a critical component of the emergency response plan called for in Section 303 of Superfund Amendments and Reauthorization Act of 1986.

Generation of Risk Control Options

The natural byproduct of the hazard identification and risk assessment efforts is the generation of risk control options. Considering the major hazards identified and the occupational safety and health characterization of the waste site, there would be risk control options generated as related to each effort. For example, propane tanks should have a safe separation distance from buildings and property lines. Ignition source control measures should also be taken in the vicinity of the storage and transfer areas. Considering the more straight-forward fire risks, there should be hydraulic calculations readily available to facilitate determination of the adequacy of the fire protection water supply in terms of design density, i.e. gallons per minute/square foot over an operating area. Related environmental risk control options could include the need for proper containment of releases and spills.

Adequate diking and drainage is key to minimizing potential environmental damage and complying with the Clean Water Act.

Considering the occupational safety and health characterization of the hazardous waste site, a potential recommendation could involve the need for an on-site source of breathing air to refill self-contained breathing apparatus. Perhaps there is a need for dike repair or improvement. A frequent area for programmatic improvement is the periodic need for hazardous material awareness training.

Development of a Comprehensive Emergency Response Plan

Having identified and assessed the potential risks and mitigated them to the extent possible through the implementation of risk control options, efforts should then be directed towards the development or enhancement of a comprehensive emergency. response plan. Included in this document should be the following:

- introduction, e.g., purpose/ scope, revision policy, distribution list;
- program description, e.g., organizational structure and chain of command, site description;
- pre-emergency planning, e.g., coordination with public authorities and private contractors;
- hazard analysis/hazard characterization, e.g., events identified, listing of wastes;
- hazard communication program, e.g., chemical inventory, material safety data sheets;
- communication and notification, e.g., internal, external;
- site control/security, e.g., facility access, guard coverage;
- evacuation routes and procedures, e.g., notification, means of egress, drills;
- emergency response equipment, e.g., types and quantities, supplies;
- personnel and area air monitoring, e.g., equipment, procedures, frequency;
- hazardous material/waste containment, control and cleanup, e.g., methods and techniques, land or water;
- personal protective and safety equipment, e.g., levels of protection, selection and types, use and limitations;
- decontamination program, e.g., work zones, procedures, equipment;
- medical surveillance/ medical emergencies, e.g., frequency and types of examinations, internal and external emergency medical services;
- training, e.g., content of OSHA and RCRA programs, frequency, trainers;
- post emergency response operations, e.g., on-site, off-site, damage assessment, restoration of the environment, waste disposal;
- public relations, e.g., authorized spokesperson, media contact list, "press kits;"
- new technology program, e.g., roles and responsibilities, program contents;
- quality assurance program,e.g., preventive maintenance, drills, audit program;
- hazardous material data sources, e.g., library, other sources; and
- appendix, e.g., detailed hazard analyses, impact zones.

Such a document would meet the requirements set forth in Section 303 of Superfund Amendments and Reauthorization Act of 1986 and the Occupational Safety and Health Administration regulations found in 29 CFR 1910.120.

Development of a safety Plan

Using information generated as part of the hazardous waste site characterization, a health and safety plan can be developed in accordance with the Occupational Safety and Health Administration regulation. This document should include the following:

- introduction, e.g., purpose/ scope, revision policy, distribution list.;
- rules and responsibilities of facility personnel, e.g., organizational Structure and chain of command, site description;
- site control/security, e.g., facility access, guard coverage;

- hazard communication, e.g., chemical inventory, material safety data sheets;
- medical surveillance/medical emergencies, e.g., employees covered, frequency and types of examinations;
- environmental, health and safety training programs, e.g., RCRA facility operator specific training, evaluation/ certification;
- personnel and area air monitoring, e.g., equipment, procedures, frequency;
- hazard control methodology, e.g., engineering controls, work practices;
- personal protective and safety equipment, e.g., levels of protection, selection and types, use and limitations;
- decontamination program, e.g., work zones, procedures, equipment;
- hazardous wastes and materials handling program, e.g., types and locations of wastes, materials handling equipment and procedures;
- RCRA facility emergency response program, e.g., emergency procedures for hazardous waste events;
- new technology program, e.g., roles and responsibilities, program contents; and
- general site safety and health policies, e.g., accident reporting, personal protective equipment.

There are similarities in the emergency response plan and the health and safety plan; in fact there is an identified need to eliminate any possible inconsistencies. Major differences include the detailed emergency procedures based on the risk screening and hazard analyses in the emergency response plan and the emphasis on hazardous waste-related issues in the health and safety plan.

Benefits

Once a corporation has adopted the techniques of risk management in the conduct of its business, there are numerous benefits to be gained. Anticipation and planning improves prevention and mitigation capabilities which can reduce the number of personnel injuries, property damage, accidental downtime and the resulting loss of revenue associated with business interruption. The exercise of risk analysis allows the evaluation of existing safety measures, and can point out weaknesses or potential problem areas in the overall safety design. In addition, human error can be an important source of risk, and risk analysis often points to positive changes in overall safety management structure and procedures. Specific benefits resulting from the activities presented above include the following items.

Improved Understanding of Facility Risks : The principal by-product of hazard identification and risk screening efforts is a more refined understanding of those events that have the potential for serious on-site or off-site impact.

Identification and Prioritization of Risk Control Options: Having identified and analyzed a facility's risks, one can then readily identify and prioritize those risk control measures that will reduce the probability or consequences associated with the events.

Development of a Comprehensive Emergency Response Plan : With limited resources for equipment and program development, technological risk management facilitates the development of a comprehensive emergency response plan that can be directed towards those risks that are more likely to occur and/or have consequences that are comparatively severe.

Development of a Health and Safety Plan : The programmatic development of a detailed health and safety plan should be based on a sound technical understanding of associated risk, whether it be for hazardous waste or other hazardous materials.

Compliance with Applicable Regulations : State-of-the-art technological risk management can be very valuable in helping a facility or a corporation comply with the regulations recently promulgated by Environmental Protection Agency (EPA) and the Occupational Health and Safety Administration. In addition, some state regulations require the application of risk assessment techniques.

In closing, it is important to note that while shipbuilding facilities present special environmental/ health/safety challenges, facility personnel are generally very eager to address them, and often serve as a catalyst for progress. Such situations present unique and very fulfilling opportunities for shipyard management and safety professionals to work together to effect changes aimed at minimizing the potential for fatalities, injuries, property damage and business interruption.

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Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee. Wisconsin, August 21-24.1990

Acquisition of Ten ANZAC Frigates

2A-1

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ABSTRACT

Australian Marine Engineering Consolidated (AMECON) of WIlliamstown Victoria was awarded a contract in September 1989 to build 10 ANZAC Frigates, 8 for the Royal Australian Navy and 2 for the Royal New Zealand Navy.

The contract and the signing by the Defence Ministers of Australia and New Zealand of an agreement for the construction of the frigates culminated six years of lead-up work but had its genesis on the shores of Gallipoli 75 years ago.

This paper addresses the lead-up activities, including the establishment of a joint project office, Australian and New Zealand Defence Committee involvement, tendering, evaluation and negotiation. The paper also provides an overview of the ship construction techniques and the division of work.

INTRODUCTION

At present Australia's surface combatant fleet consists of three guided missile destroyers (DDG), four guided missile frigates (FFG), five destroyer escorts (DE)) and 20 patrol boats.

In the mid 1980's the Royal Australian Navy (RAN) conceived a project for the introduction of New Surface Combatants to provide a capability to take over from the aging destroyer escorts. The direction of this project was focused in 1986 by a defence review conducted by Mr Paul Dibb, then the Director of the Joint Intelligence Organisation. The review was conducted within the framework of Government policy which required self reliance, a coherent defence strategy and an enhanced defence capability.

The review developed an argument for eight light patrol frigates with the range, speed and seakeeping to operate in Australia's area of direct military interest and beyond. Each ship would be able to carry a helicopter and be fitted with a range of modern sensors and weapons.

Following on from this review the Chief of the Naval Staff, Vice Admiral M.W. Hudson, introduced the concept of three tiers of surface combatants with Tier 1 being represented by the DDGs and FFGs, Tier 2 by the destroyer escorts and Tier 3 by the patrol boats. Hence the New Surface Combatant project was directed at acquiring eight Tier 2 light patrol frigates.

New Zealand's destroyer fleet requires two ships to be replaced in the mid 90's and a further two after the turn of the Century. This New Zealand requirement coincided with Australia thus there was scope for a joint venture which could achieve cost savings and common equipments.

After issue of the Dibb report the Minister for Defence announced that the Government planned to build in Australia: 6 submarines, 8 new surface combatants, mine warfare vessels, survey motor vessels and hydrographic vessels for a total value of over seven billion dollars. He also stated that the industry was to be restructured to ensure this workload is handled efficiently and is properly used as a basis for attaining an internationally competitive standard.

The Australian shipbuilding, ship repair and heavy engineering industries are recovering from years of decline and from a series of world oversupply crises. While considerable progress has been made in the rationalisation and increased efficiency of the industry sectors which produce smaller tourist, fishing and pleasure vessels, the scope and complexity of the larger projects planned will test the competence of many organisations, large and small.

PROJECT DEVELOPMENT

Development of the New Surface Combatant project to contract signing took about 6 years, the first three of which were relatively slow as the project got off the ground and the way ahead was established. Various overseas visits were undertaken to the US and Europe to investigate the ship and weapon market and studies were undertaken to refine the capability requirement.

Risk

Of importance in the process was the determination of risk the Department of Defence was willing to take. Figure 1 is a simplistic portrayal of acquisition risk.

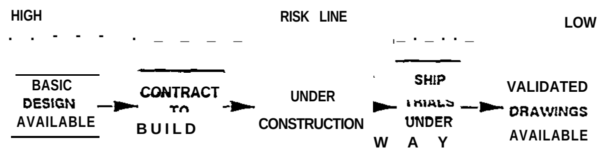

FIGURE 1 ACQUISITION RISK

To construct a ship from a set of validated drawings normally entails a low cost and schedule risk, however such a set of drawings will have taken a long time to produce with the actual design probably being undertaken 6 or 7 years previously with weapons and technological innovations naturally being of that period. At the other end of the scale the design is in the embryo stage and a high risk prevails that the ship will not be delivered on time and to budget.

Complimentary to the risk related to the design status is the risk related to ship construction. To ask an established American or European yard to build a frigate, would have entailed low risk. The same confidence was not felt for a build in Australia.

Australian warshio building is at a comparatively low ebb. The last major ship built was completed 'in 1971. Currently two FFG 7 class frigates are being constructed, but much of the process requiress re-learning of skills not used for many years.

The combination of the two risks, design and construction, required the Department, in order to have an acceptable measure of confidence that the risk could be managed. to look to the acquisition of an 'existing design', for construction in Australia. The definition of an 'existing design' was debated for some months with the 'operators' looking to the inclusion of future weapon technology and the 'production' side of the house advocating the virtues of validated drawings. A compromise was reached and a Request for Proposal (RFP) was issued worldwide with 'existing design' defined as 'one which has been constructed or which is under contract for construction by the date of closure of the RFP'.

Request for proposal.

The Request for Proposals, was issued in Dee 1986. The thrust was to establish the status of the ship offered, the capability of the ship designer/builder to undertake development of the design (noting that some designs did not belong to shipbuilders), the estimated cost for construction and to determine which two designs should be further investigated.

The 22 respondents to the RFP were:

Blohm and Voss - MEKO 200P class frigate;
Bremer Vulkan - F122 class frigate;
Flncantieri - Maestrale class frigate;
Hyundi - HDF 2000 class frigate;
Pronav France - F 2000 class frigate;
Royal Schelde - M Frigate (together with a less capable/complex Modified M Frigate);
St John Shipbuilding - Canadian Patrol Frigate;
Swan Hunter - Type 23 class frigate;
Vosper Thornycroft - Mode rnised Leander class frigate;
Yarrows - Type 23 class frigate;
Unisys Corporation - FFG 7 class frigate;
BMV Engineering - Nordkapp coastguard vessel;
Bond Cornoration - Airship Sentinel Design:
PEAB - Alternative combat system for F122 frigate offered by Bremer Vulkan and Tvpe 23 offered by Yarrows; -
Rockwell International - Assistance in commonality studies;
Boelwerf - Wielingen class frigate;
Bremer Vulcan - Reduced F122 (not an existing design)
Yarrow Shipbuilding - Mini 23 (not an existing design)
Hall Russell Proposal for Frigate design (not an existing design).

The assessment of the responses was underway when New Zealand joined the project. In late 1986 and early 1987 there was discussion between the two countries at both Departmental and Ministerial level, the outcome of these discussions being a Memorandum of Understanding signed by the two Ministers which provided for, among other things, consultation on the design, construction in Australia, a joint project office, finance on a pro rata basis for project office activities and comprehensive disclosure of relevant information between the two parties.

At the same time, the project was named the ANZAC Ship Project in recognition of the bond established between the two countries at the landing of the Australian and New Zealand Army Corps at Gallipoli in 1915. The name ANZAC has a proud tradition in both Australia and New Zealand and is most fitting for this joint project.

The project office was expanded to include New Zealand personnel both service and civilian in the team, including a civilian engineer as Deputy Project Director. New Zealand capability requirements were assessed to identify differences from the Australian requirements and a start was made on the financial sharing arrangements.

There were some differences in the Capability requirements between Australia and New Zealand. For-example New Zealand had a requirement to fit-for-but-not-with a relatively large towed array system. This system's physical size presented major problems at the aft end of some of the proposed designs. However in these early davs neither Navy had fully firmed up on particular weapon configurations so there was room to manoeuvre during assessment of the RFP responses.

After assessment and consideration by both Australian and New Zealand source definition committees it was decided to ask Blohm and Voss (Meko 200), Royal Schelde (M Frigate) and Yarrow (Mini Type 23) to further develop their proposals. These three would be later reduced to two.

Invitation to Register Interest.

As the RFP process was underway an lnvittation to Register Interest (ITR) in the construction of the ships was issued to Australian Industry.

The ITR was structured in a way that would encourage the formation of strong consortia with financial strength, with the ability to act as Prime Contractors for the construction of the ships and to provide appropritate facilities and a comprehensive range of logistic support. The involvement of an electronics/weapons firm was also encouraged through discussion with industry.

Three significant issues emerged from the ITR which dominated the selection of the two consortia to receive RFTs. These were:

a. availability of suitable facilities;

b. involvement of the overseas Designer/Weapons House; and,

C. shipbuilding experience.

There was a general problem with existing facilities which affected all respondents to a greater or lesser degree. A stipulation in the ITR called for no significant upgrading of existing facilities at Commonwealth expense.

There seemed to be little doubt that for a single-stream ship COntraCt, major facility expenditure would be needed at all venues other than at Williamstown Naval Dockvard where the FFGs were being buift. Even at Williamstown there was some doubt that the ANZAC ships could by produced in the timescale and at the required rate without an upgrade of the facilities, not to mention technical management resources. At that time Williamstown Naval Dockyard was in the process of being sold and a number of the ITR respondents were banking on obtaining the dockyard as their facility. Others proposed a green field site.

The responses showed that for sites other than Williamstown substantial upgrading would be required. All respondents proposed such investment: . some indicating that the upgrading would be undertaken on a commercial basis, regardless of winning the ANZAC contract, whilst other suggested that costs would be recouped by the expected improvements in productivity.

Whilst the ANZAC contract would undoubtedly dwarf any other contract held or gained by the winning yard for the foreseeable future, there is no doubt that the cost of upgrading would fall to the Commonwealth regardless of whether that cost appeared as a specific line item in the tendered price or whether it was subsumed in the total price. The question of whether or not the costs of upgrade could be justified depended upon several factors. One of those was the opportunity to amortise facility costs over a considerable number of ships. This is one of the strengths of the ANZAC program - the large number of ships Will enable considerable investment costs to be amortised.

The two consortia selected as a result of the ITR process were Australian Marine Engineering Consolidated (AMECON) and Australian Warships Systems (AWS). These two consortia had to wait until the Department selected two of the three designs before they could combine with the designers.

The strategy adopted was to ask each of the building consortia to combine with a designer. This resulted in two powerful groups, each having its own builder and designer and each having sufficient strength to equally compete for the contract.

Design Development Contract.

The three desianers were tasked with expanding on their technical and cost proposals. On the technical side modification of the designs were investigated to accommodate special Australian/New-Zealand requirements and variations in cost were looked at for different weapon configurations and ship delivery rates.

There were advantages and disadvantages related to each of the three final proposals. There was little to choose between the three, however on balance the Blohm and Voss MEKO 200 and the Royal Schelde M Frigate were preferred as the two designs to go forward to the next phase. Both designs were assessed as being acceptable to the Navy.

There had been discussions between the two shipbuilding consortia and the three designers while the selection process for the two designs was underway; therefore on announcement by the Government of the two successful designers it did not take long for the final combination to be settled. AWS joined with Royal Schelde and AMECON with Blohm and Voss.

Request for Tender.

Although the ITR and RFP were important preliminary documents the Request For Tender (RFT) for the Prime Contract was the vehicle that implemented the strategy and accorded with Government policy to develop two centres of concentration of major naval shipbuilding and with Defence aspirations on shipbuilding techniques, technology transfer, logistic support and industry involvement.

Because of the extent of the work required to provide tender information the Department awarded a design development contract to each tenderer. This contract covered the provision of a range of information which could be rolled into the tenders for consideration during the evaluation.

Of significance in the tender and development contract deliverables were the build strategy, Australianisation, technology transfer, logistic support and cost/schedule management.

Another strategy utilised was to divulge the unit ship price which the Government was prepared to meet. This had the effect of keeping a lid on the project cost and demanded that the tenderers look very closely at the equipment to be offered and the existing build strategy to see where cost cutting changes could be introduced. Coupled with this was the Governments desire to spread the work around Australia and New Zealand.

In order to try and steer both consortia down a track that could have significant cost savings the Production Branch of Navy invited Mr. Lou Chirillo of Chirillo Associates to Australia to present to both the Department and the tenderers the latest techniques in ship construction. These presentations provided the necessary incentives for the tenderers to embody advanced construction techniques, thus the cost per ship became achievable and ways emerged to spread the work throughout Australia and New Zealand.

The Australianisation of the design and the manufacture in country of a percentage of the high tech weapon, communications and computing equipment was designed to provide technology transfer. The RFT was specifically designed to ensure that the tenderers' proposals could be accurately assessed both for the percentage of Australian/New Zealand content and the technology value of that content.

The effectiveness of Australia's armed forces depends to a significant extent upon maintaining a sufficiently high level of technology in critical capabilities. This includes the ability to acquire, operate and support advanced military equipment. High technology equipment offers potential for increased capabilities and reduced manpower requirements. However acquiring high technology equipment is not an end in itself, there is a need for indigenous Australian development, drawing on overseas experience where appropriate. Intelligence, surveillance and sensor equipment together with associated command and control systems have priority for local technology development because they need to be tailored to the local requirement. Australia's capacity in the operation, modification and maintenance of advanced equipment is relevant to the regional military situation and self-reliance. It is particularly important that advanced technology equipment should be supportable from local resources.

A critical area of support is electronics, particularly the software needed to support modem weapon systems. Australian industry is currently increasing expertise in this advanced technology area. The logistic support requirement also includes the production in Australia of high usage spares and ammunition where the cost penalty is not excessive.

The RFT also required the tenderers to show the level of Australia's design resources which would be used not only in design changes but also in the support area. Both tenderers being required to employ Australian design personnel, including Defence designers in the overseas design location as well as setting up a local design capability.

Integrated Logistic Support (ILS) is usually a very significant element of project cost. The ANZAC ship project is no exception. When looking at project costs it' is 'very j easy to 'save' money by cutting ILS costs. There is no immediate affect on the project, in fact the project may never be affected because by the time a problem occurs due to the cost cutting the ship is out of project hands and the operators have to solve the problem and pick up the tab. To spend money in the early part of a project to set up a solid support base saves money in the longer term.

With an all up cost of A$3500m contemplated and a requirement that a high percentage was Spent in Australia/New Zealand it was imperative that an efficient cost and schedule management system was used by the successful tenderer. Some form of control was required to not only ensure that the shipbuilder has his house 'in order but also that all of the major sub-contractors reported their performance in a common format.

The cost/schedule control requirements of the US DoD Instruction 7000.2 were imposed on the Prime Contractor and on major in-country sub-contractors. For overseas major sub-contractors a form of cost/schedule status reporting to US DoD Instruction 7000.10 was required. Both of these instructions are widely used in the US and will not be described here.

In order to ensure that the total contract was correctly defined the Department devised a Contract Definition and Monitoring System (CDAMS). CDAMS is designed to provide to the Department a full contract definition of scope and price, monitoring of progress and the means for the contractor to claim payment against achieved progress based on the structure of the Cost/Schedule Control System. CDAMS also provides listings of such aspects as Australian and New Zealand industry involvement, offsets, foreign currency and vesting.

One of the principal reasons for developing CDAMS was that the contract is on a variable price basis (allows variation for exchange rate and escalation). CDAMS allows the client to monitor price rather than cost. Of fundamental importance is that CDAMS defines the data base which is then used in the Contractors Cost/Schedule Control System. This single data base is the source of all reports and forms the complete' definition of the work to be performed during the contract.

Evaluation.

The tenders closed in January 1989 and the evaluation process got underway. It was imperative that probity not only be maintained but also that it be seen to be maintained. In addition there was the requirement to ensure that both Australia and New Zealand officers were involved in each of the evaluation teams.

There were six evaluation teams covering:

Operation and Design

Organisation, Management and Production

Integrated Logistic Support

ANZ Industrial Involvement

Financial and

Contractual

Each team developed its own Work Breakdown Structure (WBS) for the evaluation task. The Organisation Management and Production team had six groups in its structure at level 2. An abbreviated WBS is shown at Figure 2.

Each Team produced its own report for Defence committee considerations. The Defence Source Definition Committee (DSDC) was expanded to include New Zealand officers, thus although New Zealand has an equivalent committee and each team report was presented to each committee, the expanded DSDC carried the principal responsibility for evaluation and for determining the procedures to be adopted for requesting final offers.

Negotiations.

As the DSDC was deliberating, negotiations were started with each of the two tenderers.

During this period members of the DSDC visited each of the consortia for discussions and viewing the facilities. This enabled committee members who were not familiar with shipyard operations to come to grips with the evaluation task. The negotiations covered each term and condition of the proposed contract. Working groups were set up to investigate contentious issues and to look into the various options proposed by the tenderers and the Department.

Best and Final Offer.

Near the end of the negotiations and DSDC deliberations the tenderers were asked for their Best and Final Offers (BAFO). These offers were based on the negotiated agreements reached over the previous weeks and a defined ship configuration. Deliberate and extreme care was taken to ensure that no one 'moved the goalposts'. Receipt of the BAFO's started a new round of evaluations. This time however the principals of each of the evaluation teams undertook the majority of the task concentrating on the issues marked by the DSDC. Predominant in these issues was that of cost and it was cost that made the pendulum swing in AMECON's favour. AMECON came in the cheaper of the two and was selected to undertake final negotiations for the prime contract.

PRIME CONTRACT

The final development of the Prime Contract continued with AMECON from where it was left before the BAFO. Outstanding terms and conditions were negotiated and working parties tidied up various annexes for such aspects as ship specifications, logistics, management, build strategy, facilities etc. The build strategy was of particular concern

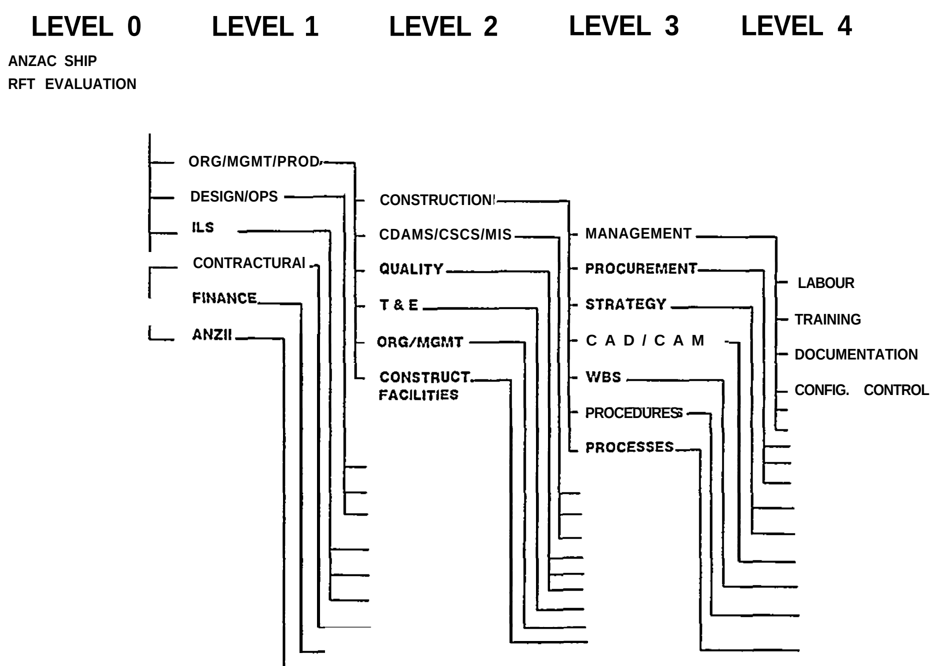

FIGURE 2 ABBREVIATED BREAKDOWN STRUCTURE

because although agreement had been reached on price it was of note that to achieve this price with the attendant requirement for Australianisation of the design and local industry involvement a considerable amount of up-front engineering was required to change the MEKO detailed design from that being used in West Germany to that required for construction in Australia.

The MEKO 200 ANZ is shown at Figure 3.

There are two interesting construction techniques embodied in the Australian MEKO 200 (MEKO 200 ANZ). The first, and that which was emphasised by Blohm and Voss, is the use of function units, particularly weapon units, which allows a relatively easy mix-and-match without significant change to the ship.

The second construction technique embodies the concept of module construction coupled with high levels of hot and cold pre-outfitting, zone outfitting methodology, and group technology. This method makes use of the excellent access that is available to the work place through large openings in the decks and ends of the hull modules. Figure 4 shows the MEKO 200 ANZ hull and superstructure module configuration.

The full extent of zone outfitting and group technology will not be achieved until part way through the build program, but already AMECON is putting some of these techniques to work in the FFG construction program.

The MEKO steel work drawings are being developed to enable all hot outfitting of modules, including in-tank pipework to be completed before the blast and paint operations. The modules will be extensively pre-outfitted with equipment and services before they are consolidated on the building berth and before the separate function units are installed.

Construction and pre outfitting of some of the six hull modules and six superstructure modules will be carried out away from the AMECON shipyard . This provides production flexibility, improved schedule performance and reduced critical path dependence on resources at the shipyard.

The build strategy plans to use sites in Newcastle and in New Zealand. These sites have infrastructure which will not require extensive development of facilities and personnel to meet AMECON's requirement. Should a site become inefficient there is flexibility to relocate work to another. The build strategy provides continuous competition and inherently mitigates risk. Within the build strategy AMECON will construct the two machinery modules of the hull and the combat/communications/navigation module of the superstructure at Williamstown.

The present facilities at Williamstown are suitable for FFG construction, however for a programme as extensive as the ANZAC programme it is recognised in the Prime Contract that some upgrading is required. A feature of the upgrading is the installation of a shiplift facility. A shiplift will also

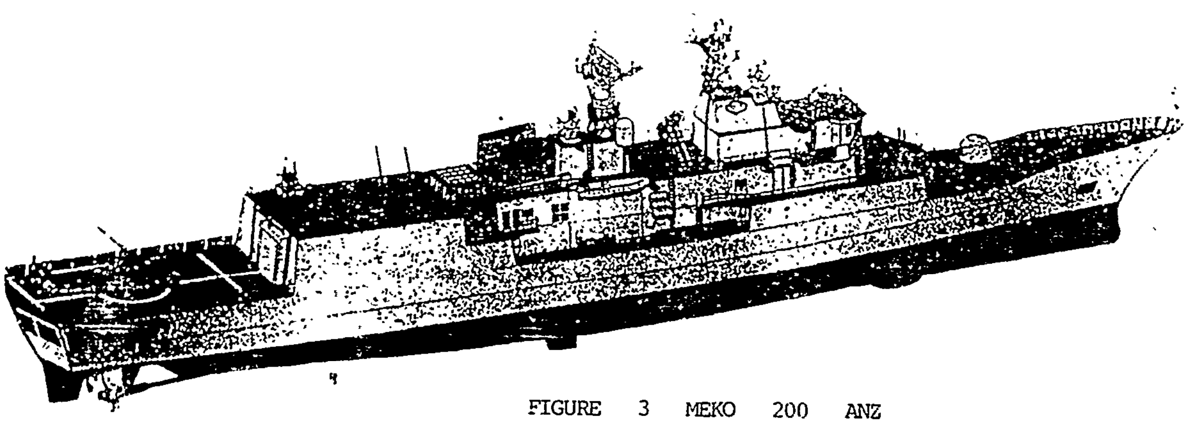

FIGURE 3 MEKO 200 ANZ

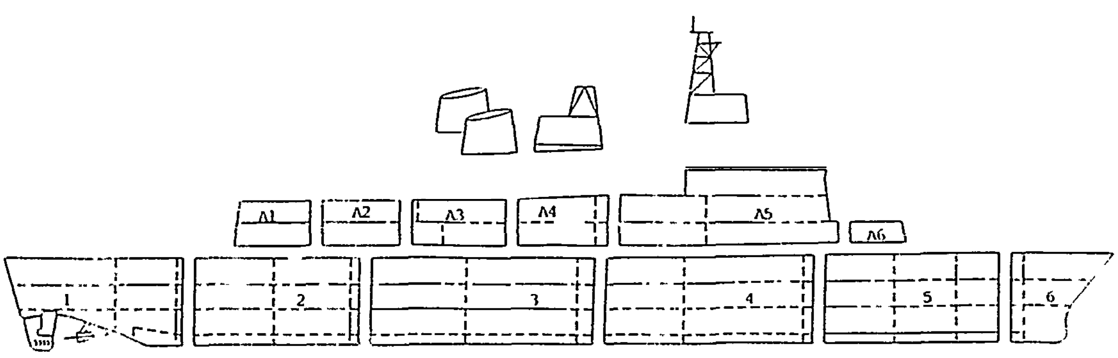

FIGURE 4 MEKO 200 ANZ MODULES

provide AMECON with the capacity to receive sub-contracted modules by transfering from a special purpose self levelling sea-going barge by means of a multi-wheeled transporter. Additionally the shiplift will provide an alternative to the Graving Dock for the docking and launching requirements of the testing program, as well as capacity to dock ships completed earlier in the build programme.

The up-front engineering task largely dictated the delivery programme which is shown at Figure 5. With delivery of the first ship mid 1995 there is time before cut steel for documentation to be produced to facilitate integrated hull, outfitting and painting and procedures for group technology to be developed. The accurate and timely completion of this up-front engineering is absolutely vital to the success of the program.

AUSTRALIA/NEW ZEALAND TREATY

Although a Memorandum of Understanding had been signed at the beginning of New Zealand's involvement in the ANZAC ship project it was necessary that a further agreement be entered into, after the Prime Contract signing between the two Governments. Such an agreement called the 'Agreement Between Australia and New Zealand Concerning collaboration in the Acquisition of Surface Combatants for the RAN and RNZN' (also called the Treaty) was signed by representatives of both Governments on 14 December 1989.

The Treaty details management arrangements, payment obligations for each country, arrangements for Australian and New Zealand industry activities flowing from the Prime Contract, arrangements for logistic support, and other matters of a contractual nature regarding the rights and obligations passing from Australia to New Zealand.

The responsibilities, authorities and reporting requirements for the Joint Project are contained in a Project Management and Acquisition Plan (PMAP) which stems directly from the Treaty. The top level management arrangements are shown at Figure 6.

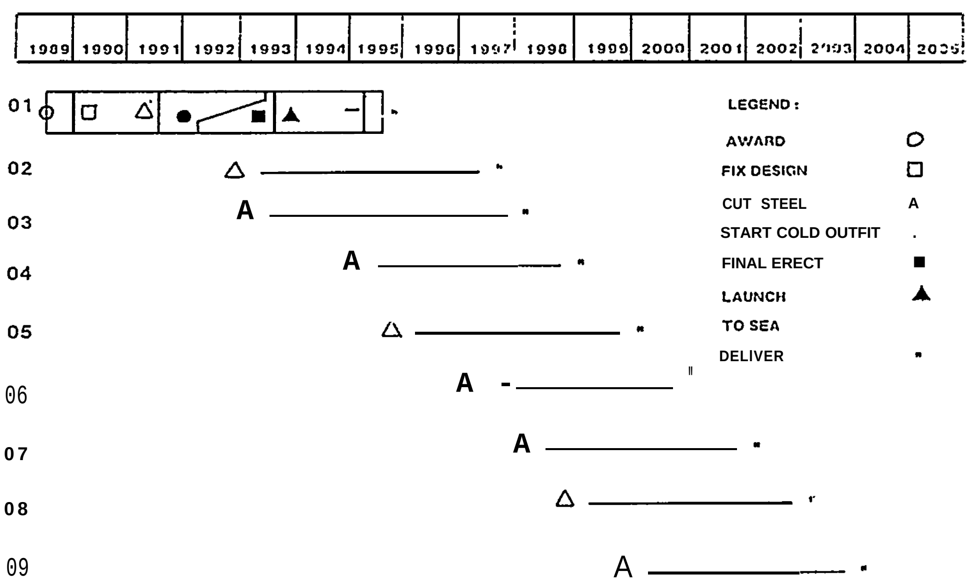

FIGURE 5 ANZAC SHIP PROGRAM

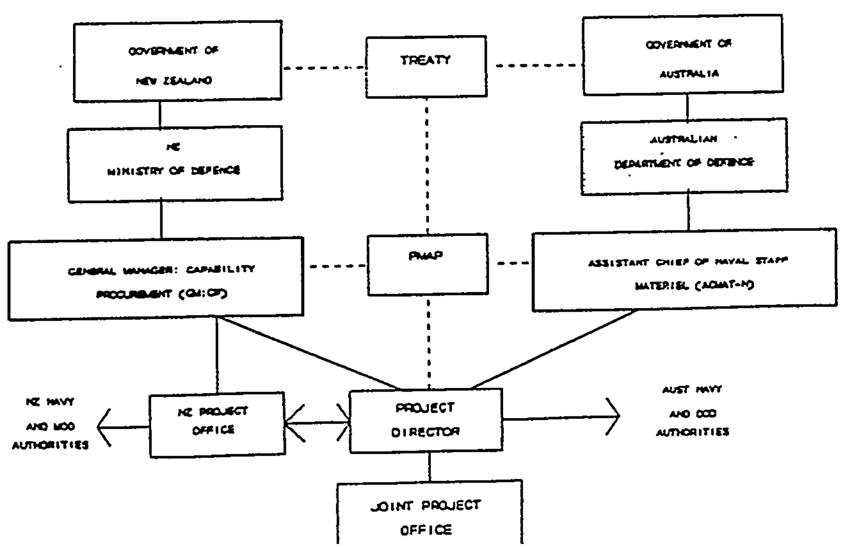

FIGURE 6 TOP LEVEL MANAGEMENT ARRANGEMENTS

EXPECTATIONS

The Departments expectations from the ANZAC ship contract are high. As with any contract, delivery on time and within budget is expected to be achieved and the ANZAC ship contract is no exception. However, in addition to this the Government's aim to foster two centres of concentration of shipbuilding (Williamstown in Victoria and Newcastle in New South Wales) and further develop the Australian defence industry are of equal importance. The achievement of this aim will be a once off activity with the restructured industry vying for both Australian and offshore shipbuilding contracts.

The logistic and build strategy arrangements in the contract should, with trust between all parties, enable all expectations to be achieved.

CONCLUSION

The ANZAC Ship program is a very large commitment by Australian standards. A single variable price contract for 1O ships requires very careful management to control configuration and costs. Achievement of Australian and New Zealand industry involvement targets is a key aim. In order for the contractor to make a reasonable profit he will have to introduce modem shipbuilding techniques and closely control his sub-contractors.

Finally, it should be pointed out that the strategy employed to achieve the ANZAC contract was, to some extent, dictated by Government and industry objectives. It worked well for the project, but later contracts should be somewhat simpler in their nature.

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306
Paper presented at the NSRP 1990 Ship Production Symposium, Pfister Hotel, Milwaukee, Wisconsin, August 21-24, 1990

Task Definition as a Route to Effective Production of Modern Warships

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ABSTRACT

Construction of a modern warship can occupy a period of more than three years, during which time more than three million manhours may be expended, and it is necessary to control the acquisition, production and installation of some 250,000 items of material and equipment.

To execute the process effectively requires an efficient means of planning and control, and this paper describes the approach to that task adopted by a United Kingdom shipyard.

The concepts of Build Strategy, Work Packaging, Materials Definition, Process Engineering and Labour Cost Control, as related to the shipyard's organisation structure are explored. The paper describes the establishment and operation of a system of planning and control based on task definition.

1. INTRODUCTION

In recent years warship building in the United Kingdom, as elsewhere, has undergone considerable change as shipbuilders strive to achieve the goals of reducing costs and delivery time, whilst increasing product quality. Major strides have been made in developing warship designs which are production kindly and substantial investment has been made in a wide range of improved facilities for their construction. These developments contribute to the achievement of the shipbuilder's goals, but in themselves they cannot bring about the step-change in warship productivity which is required in the face of competition, not only from our partners and traditional competitors in Europe, but from new sources of vigorous competition elsewhere in the world.

To realise the potential for increased productivity inherent within current and developing designs and conferred by modern facilities, it is essential that the shipbuilding process is effectively and efficiently planned and controlled.

It is recent developments in this field which are the subject of this paper.

2. BACKGROUND

2.1 Fundamentals

To achieve effective and efficient control of the shipbuilding process it is first of all necessary to define the bounds of that process. In recent years considerable attention has been paid to design for production, in recognition that the effectiveness of the production process is directly influenced by the outcome of design decisions. Further, there has been increasing understanding that the timing of these decisions can have a major impact on shipbuilding productivity. The process which must be planned and controlled, therefore, is that which begins with the conversion of concepts and basic designs into functional and detailed design information and which concludes with the setting to work and commissioning of the vessel.

The techniques of advanced outfitting and the principles of planning and control by means of planning units and production stages are now widely understood within the shipbuilding industry. It is upon these foundations that the policies and systems for task definition now in use within Swan Hunter Shipbuilders, and described in this paper, have been built.

2.2 Objective Setting

The highest level of project-related objective setting is that at which the Build Strategy, Project Plan and Quality Plan are prepared.

The Build Strategy provides a basis for co-ordinated action by all departments of the company throughout the execution of a contract. It identifies policies and decision rules which specify how the contract is to be tackled and is the vehicle for communicating these policies throughout the company. Its scope may include a wide range of issues, from the influence of a proposed construction sequence on cashflow (or vice versa), through requirements for detailed design arrangements and information formats to suit preferred production practice, to the identification of cost-effective building procedures. It highlights areas where resources or facilities may be inadequate for the execution of a project, as a basis for defining development needs.

The Project Plan is the primary planning document for any project. It is a comprehensive network interlinking the activities of all pre-production and

production departments throughout the life of the project, from pre-contract tasks to ship delivery.

The Quality Plan is the co-ordinating document for the process of planning for quality within the company's Total Quality Management system. It describes the procedures to be adopted and identifies the inspections and tests to be performed to obtain assurance of the specified quality standards.

These documents form the starting point for the process of task definition, beginning with the identification **of** major planning units and the key stages of production and leading ultimately to the definition of individual work packages.

2.3 Organisation

Concurrent with the development of the system of task definition utilised within the company has been the evolution of a system of ship production based upon the principles of project management. Each contract is under the control of a Project Management Team responsible for its planning and execution. In the case of a large contract, such as that for a new construction vessel, this team operates as two supporting organisations, one charged with contract management, detailed planning and quality management; and the other with short term scheduling, ship construction, setting to work and commissioning.

This project structure is supported by the various functional departments in the company, each of which is required to plan and manage its resources to meet the often simultaneous demands of a number of project teams.

2.4 Environment

The' working environment to which the system of task definition is applied is one in which traditional work demarcations in both production and technical functions have been removed. This is an essential prerequisite of effective task definition in which the criteria for work package definition include location, timing and process and are not influenced by trade demarcation.

In practice this means that tasks, as defined in work packages, can be allocated to composite teams of interchangeable craftsmen, headed by team leaders, and that resourcing of detailed production schedules based on budgeted work packages is simplified.

3. DEVELOPMENT

3.1 Initial Steps

By the early 1980s, in response to the need for systems of planning and control as identified in section 2, development and use of technical systems such as computer augmented design and manufacture (CADAM) was being supplemented by substantial investment in production administration systems. By early 1985 these systems had reached a stage of development at which they could be used to support initial application of the techniques of work packaging and task definition to ship construction. At the same time, the company's programme of work station development was gathering pace and leading to proposals for the creation of dedicated work stations. This process was particularly advanced in the area of steel fabrication.

3.2 Implementation

The area chosen for the first implementation of work packaging and task definition was the Block Construction Facility. There was some feeling that this was once again a case of enhancing a part of the shipbuilding process which had received considerable investment in the area of methods and processes in previous years and which was not, in fact, the most significant cost generator in warship construction. However, the advantages of starting in this area were considered to outweigh this drawback. Those advantages were seen to be:

i) that it was an area with an already high level of material definition and where the concepts of interim product manufacture had been implicitly applied for some time:

ii) that it was an area with previous experience of process definition:

iii) the process of work station development had advanced further in this area than others; and

iv) that it was an area which carried out a key mainstream activity and in which delivery schedules and quality have considerable effect on downstream project activities.

In order to keep the project manageable, work packaging was initially confined to main structural fabrication, and the areas of minor steelwork production and pre-outfitting were not addressed.

One of the most important features of the system of work packaging is the ability to accurately measure expenditure against tightly defined

packages of work, with pre-determined budgets, and to readily collate non-productive costs from whatever cause. This led to an understandable concern on the part of the system users that they may be subject to an exceptional level of management scrutiny. It was necessary to allay these concerns before implementation could proceed and this was done by giving a commitment that, in the first instance, the detailed analysis of work package returns would be restricted to the Block Construction Facility management, who would use the information as an aid to the progressive reduction of non-productive costs.

In the event this arrangement worked very well, and long before fabrication of the first ship on which the system was applied was completed, information was being generated which enabled both improved accuracy in the budgeting of subsequent activities and identification of areas for management attention to reduce costs. The extent of the success can be measured by the fact that the same users who had initially expressed concerns about the system now express the point of view that to maintain their level of control, it is essential that all subsequent contracts be treated in the same manner.

3.3 Review and Expansion

When the process of work package definition commenced, in early 1985, the task was allocated to the Operations Control section of the Block Construction Facility. As the benefits of the process became apparent, it was obvious that major advantages would accrue from its rapid extension to cover further aspects of the shipbuilding process. Therefore, in early 1987, a Work Preparation Department was created, incorporating existing Mould Loft and Production Engineering functions and accepting, from the Operations Control function, the responsibility for the creation of the majority of work packages, the only exceptions being those for stockyard and treatment tasks, and service activities.

At this point the process was extended to cover the manufacture of minor steelwork items and advanced and pre-erection outfitting activities. By the end of 1987 the application of the process was further extended and the Work Preparation function accepted responsibility for creating work packages for all on-board outfitting activities.

Initial work centred around the establishment of operating procedures for the creation of work packages and the identification of improvements to the company's core material control systems to simplify the process of work package creation. Procedures for work package creation were kept under continuous review, and in less than two years developed from a combined computer and paper based system to an essentially paperless system.

The aspects of work packaging dealing mainly with material and information definition were the first to be addressed, with only limited consideration of production processes, other than in the steel fabrication area. However, as the newly formed teams producing outfit work packages gained experience with the system, they began to build on their practical experience to extend process definition to other areas. First steps included development of pipework installation sequences, for use both as an aid to production, and to assist operations control personnel to determine the consequences of material shortfalls prior to work package scheduling. Simultaneously, effort was directed to identify work package interdependencies at the block outfitting and on-board outfitting stages, as an aid to scheduling. By early 1989 the outfit teams had also taken responsibility for the creation of work packages to support the production of outfit equipment modules in the Central Manufacturing Facilities.

The system was applied progressively, and contracts which were partially complete at the time of implementation were not fully work packaged. To facilitate cost recording for activities which were not work packaged, a series of work package number/job number cross reference lists were produced to meet the requirements of the Labour Cost Control System (see Section 5). In some areas partial application of the system was effected by the use of work package headers - work packages with only brief descriptions of the job and no material definition or manhour budget, against which costs could be recorded.

4. SYSTEM DESCRIPTION

4.1 General

The definitions of the terminology used within this and subsequent sections of the paper are given in Section 4.2, and figure 1 shows how a work package is related to both product and location.

4.2 Definitions

Cost Centre. This is a designated area within which the responsibility for controlling costs, monitoring progress and controlling resources is allocated to a nominated manager.

Examples of cost centres are:

Plate Production
Unit Pre-outfitting
Hull Construction
Ship Outfitting (Weapons Compartments)
Berth Cranes and Transport
Pipework Manufacture

Work Station. Each cost centre is sub-divided into smaller defined areas. These areas *are* under the control of a single supervisor and can be allocated in one of three ways:

i) Machine orientated work station.
ii) Process orientated work station.
iii) Activity orientated work station.

Examples of work stations are:

Section Forming Machinery.
Welding of Bulkheads to Decks Downhand within the Fabrication shop.
Installation of Machinery at the Blocking Stage.

Testing and Commissioning of Weapons Equipment.

Planning Unit. This is a sub-division *of the* ship, *utilised for* planning and control. A planning unit may be one of the following:

A single Steel Assembly
Pipe Module
Equipment Module
All or Part of a Ship *Zone*
Hull area

(see figure 2)

In the case of steel assemblies, a hierarchy of planning units is defined which results in a system denoting each interim product level:

Minor Assembly
Sub Assembly
Assembly
Fabrication
Unit
Block

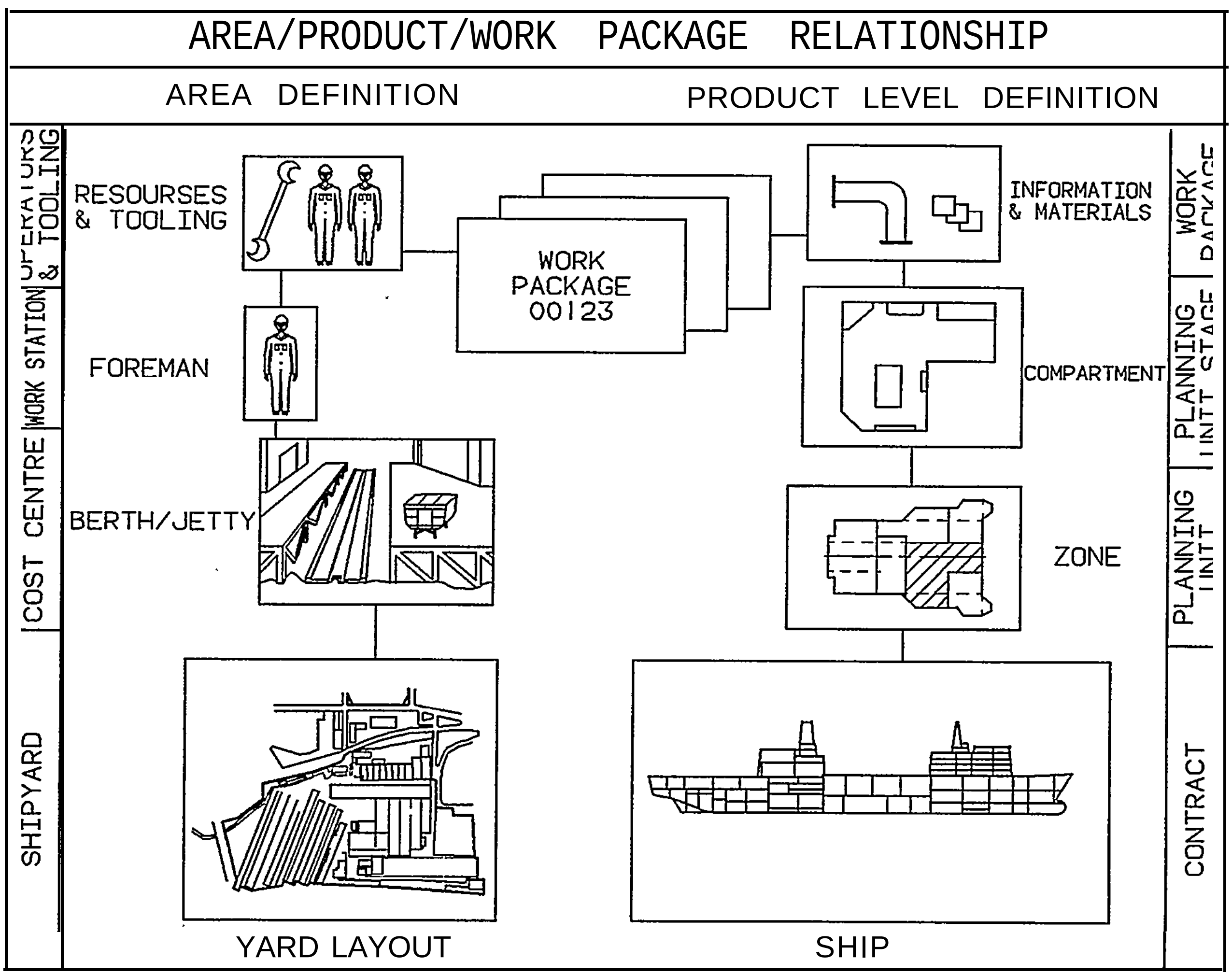

Figure 1 Area/Product/Work Package Relationship

These planning units *are* used for precise definition, allocation and marshalling of materials and also form the basis for establishing the labour cost control system in conjunction with work packages.

Zone. An area of the ship considered to be a suitable sub-division for material control, labour cost control and material installation. There are two characteristic varieties:

i) Spatial Zone
ii) Activity Zone

A spatial zone has boundaries of decks and principal bulkheads, i.e. a group of compartments (see figure 2).

An activity zone need not be spatially limited and covers all work under a specific activity. Examples are:

Shaft Installation and Alignment
Reeving-In of Electric Cable
Berth Preparation, Launching and Mooring

Hull Area. For the purposes of technical definition and materials procurement, groups of adjacent zones are designated as Hull areas. These larger planning units are an aid to planning activities at the early stage of technical definition (see figure 2).

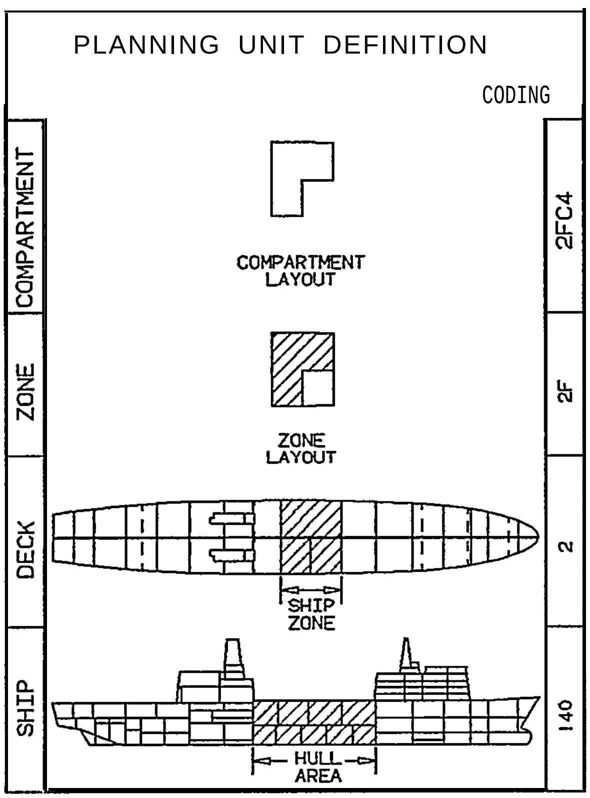

Figure 2 Definition of Planning Units

Work Package. A quantity of work to be carried out by a group of men, reporting to a single supervisor, at a defined work station at a specified time and within which monitoring of progress is not required.

Stage. (Planning Unit Stage and Zone Stage). All stages of production are identified, from component manufacture through assembly and installation to testing and commissioning. A series of stage codes exist for each planning unit and these can be grouped as follows:

Stage Codes	Description
A - G	Block Construction
H - K	Hull Construction
L - P	Ship Outfitting and Commissioning. (Graded Compartments)
R - V	Ship Outfitting and Commissioning. (Non-graded Compartments)

Material List By Fitting. (MLF) Master lists which identify the complete kit of parts for the ship. As each item is identified during the technical definition stage of the design engineering task it is recorded on the appropriate computer system (OMCS or SMCS, see sections 5.2 and 5.31), is linked to intended stage and planning unit and is allocated a unique part number.

Items listed as MLF entries fall into three basic categories:

a) In-house manufactured items, but not the *raw* materials from which they are produced;

b) Bought-in items: and

c) Free issue materials or embodiment loan items.

4.3 The Work Packaging Process

Methods definition and process analysis are the keys to ensuring that the tasks to be defined are engineered in such a fashion *as* to allow production supervision to concentrate upon the performance of the task with minimum distraction.

The identification of the work content within a work package is the key to successful task definition. A series of work instructions for process engineering staff provides rules for task definition. These work instructions allow the process engineers to define tasks of a magnitude which can easily be controlled. The current target for the average *size* of a work package is 250 manhours or a maximum duration of 4 weeks, whichever is most appropriate.

The basic tools of the *process* engineers are the documents defined in Section 2.2:

i) The Contract Build Strategy:
ii) The Project Plan: and
iii) The Project Quality Plan
Supported by:
iv) Process Engineering Work Instructions; and
v) Production Process Standards

Detailed examination of the Build Strategy allows the process engineers to elicit the correct planning unit, stage and/or zone for the task requiring definition. From the engineer's knowledge of the task to be defined and with the information contained in (i) to (v) above, the creation of a work package *is* carried out in the following sequence.

i) Selection of the planning unit and stage.

ii) Definition of the tasks to be carried out within that stage.

iii) Examination of each task and its material requirements.

iv) Grouping together of like work requiring similar or identical processes.

v) Estimate of work content and duration.

vi) Apportionment of tasks into acceptable sizes for individual work package types.

vii) Raising and detailing of work packages on computer system.

TABLE I : WORK PACKAGE ELEMENTS

ELEMENT	DESCRIPTION
a) Planning information	
Work Package Number	A unique five digit alpha-numeric code.
Work Package Title	A 30 digit title for the work package to allow ease of identification.
Planning Unit	A four digit alpha-numeric code to identify the planning unit.
Planning Unit Stage	A single digit alphabetic code to specify the stage.
Cost Centre/ Work Station	A four digit alpha-numeric code specifying the location at which the work is to be carried out.
Scheduled Date	A scheduled open and close date for commencement and completion of the task, i.e. a time window.
Actual Dates	The actual dates work is started and finished.
Work Type	A single alphabetic code defining broad categories of work.
Work Content Parameter	The measurable work content parameter for the type of work to be defined.
Manhour Budget	The product of the required performance rate for the work station and the work content parameter.
System Codes	Three digit alpha-numeric codes which allow automatic apportionment of recorded work package costs into system costs for accountancy and estimating purposes.
b) Materials Definition	A list of all the materials necessary to carry out the defined task. This list *is* produced partly from MLF automatically produced for major items and in the form of text for supplementary minor items of inventory
c) Supplementary Information	Listing of the relevant work instructions, drawings, NC information and work station information, including the issue number used to define the work package and cross referencing where applicable to previous and subsequent work packages. Any further specific process instructions and special task requirements.

viii) Allocation of parts to work package identity.

ix) Addition of any supplementary information.

ease of complete work package to Operations Control for subsequent budgeting, scheduling and materials validation.

The elements of a work package are defined in table I. These elements are all stored in a computer and subsequently appear on the printed work package documentation.

4.4 Operation and Administration of Work Packages.

Process engineering staff create work packages and define the work, including specifying work content. Operations control staff estimate the budget manhours and determine planned commencement and completion dates.

On a rolling four weekly basis the Operations Control Department produces cost centre/work station schedules, directly from the computer system, which list all the work packages to be started within the specified period. These schedules are issued to the relevant area supervision and management along with the work packages, the relevant work instructions and a three part perforated control card.

The decision as to the exact date at which each work package is to commence, within the specified window, is made by the area supervisor taking due cognizance of labour and materials availability. When the supervisor is ready to commence the work package, he records the start date on the first portion of the control card, signs it and passes it to the operations control staff, who enter the actual start-date into the computer system. This acts as a trigger to allow costs to be recorded to the work package via the automated time recording (ATR) system.

Upon completion of the work package, the supervisor enters the completion date on the next portion of the control card and passes it to the operations control staff, retaining the final portion for his own records. This completion date is fed into the computer and similarly acts as a trigger to stop the allocation of costs to the work package.

As the definition of a work package (Section 4.2) states, monitoring of progress within work packages is not

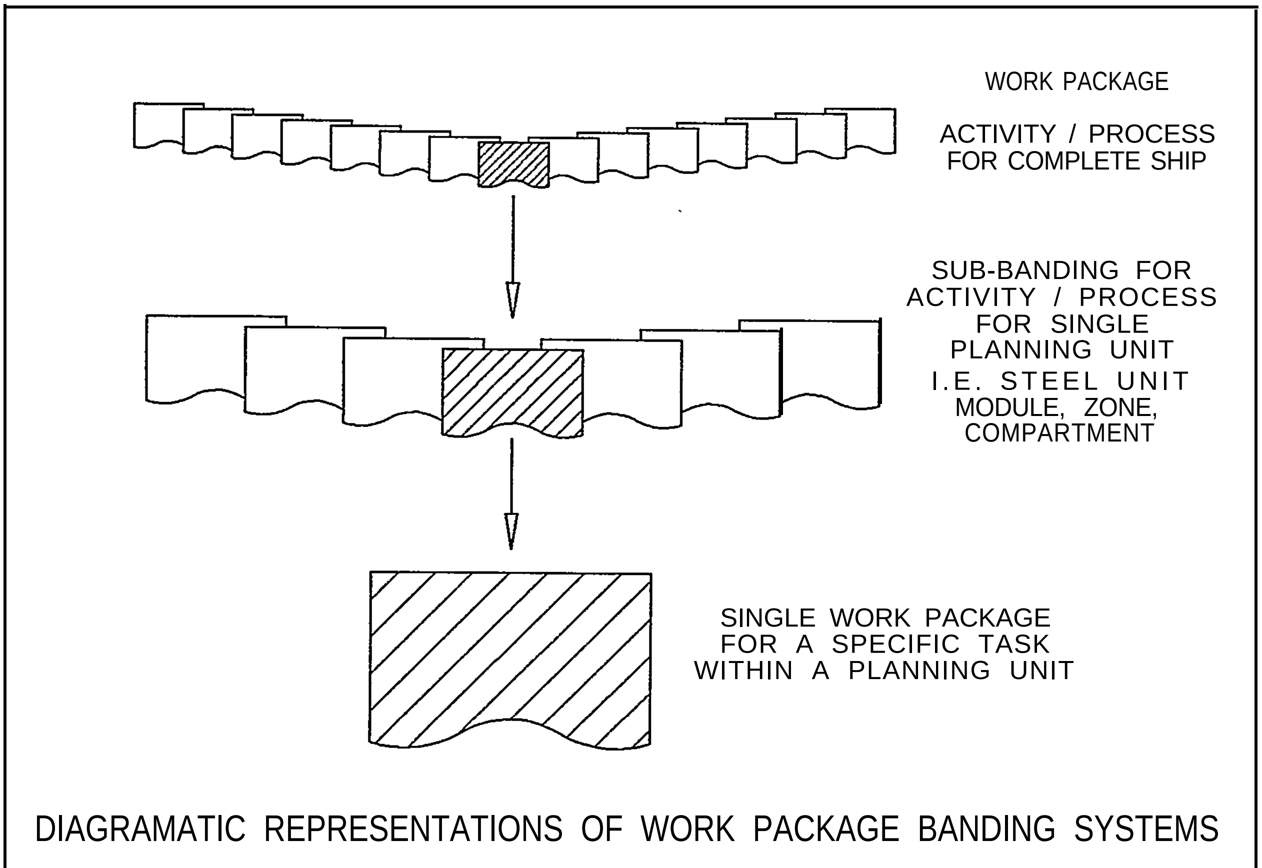

Figure 3 Work Package Banding

carried out and production progress is measured only in terms of completed packages.

If **for** some unforeseen reason a work package cannot be fully completed, the supervisor can close the work package but must specify any incomplete work, including any delinquent items not fitted, to the operations control staff. The work package budget is subsequently reduced to suit and the outstanding work transferred to a new work package along with the appropriate manhours.

The system is also extensively used to monitor unplanned work, machine breakdowns, re-work, rectification due to material deficiencies etc., by raising work packages to identify these activities for analysis purposes.

It can be seen that administration and manipulation of the work packages for a contract can be a large task, with many thousands of packages per ship. It has been necessary therefore to pre-define specific groups of work package numbers into bands allocated to a specific group of tasks or work station. Within these bands sub-groupings define planning units within which work packages define particular tasks (see figure 3).

These pre-defined number bands allow easier identification of work packages for specific work stations than would be the case with simple sequential number allocation. They also enable the computer to sort work packages by bands and produce the various levels **of** rePorts indicated in Section 4.5.

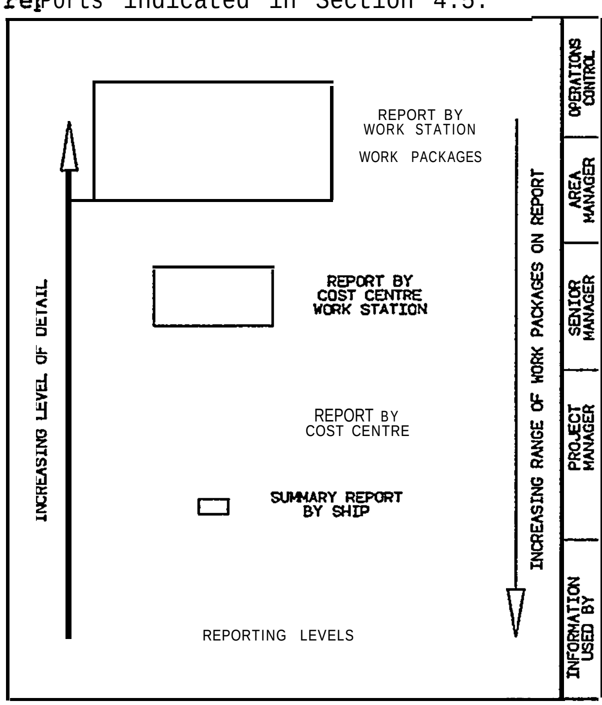

Figure 4 System Output Levels

4.5 Svstem Outputs

System outputs fall into two distinct categories:

production information used for scheduling materials marshalling and task execution: and management information used to monitor the production process.

4.5.1 Production Information. The production information related to each work package consists of a print out of the work package elements identified in table I. supported bv a codv of the flow process diagram produced by the Process Engineer during the creation of the work package, copies of the necessary drawings and, where appropriate, numerical control (NC) information.

The computer print out includes an element of text describing the production process and identifying appropriate standards. Copies of standards are held in each work area.

4.5.2 Management Information. The system has the facility to generate reports showing planned and-actual achievement and expenditure by planning unit or by location, and these reports are routinely produced on a weekly basis for the appropriate production management. In addition, managers *can* call-off specific reports to facilitate the tracking of costs of unplanned work or re-work.

Managers or operations control staff can interrogate the data on any particular contract to produce status reports at any level within the system. Example of routine reports are:

i) work package status summary at a work station:

ii) work packages open at a work station:

iii) work packages to start within specific time limits: and

iv) work package status reports by planning unit.

Output from the system can be at varying levels, from a listing of all the components for a specific work package, to a summary of work package status across a contract (see figure 4).

5. RELATED SYSTEMS

In order to fully utilise the work packaging system, direct or indirect support from a number of related systems is necessary. The links between the systems are shown in figure 5 and a brief description of each is given below.

5.1 Project Resource Evaluation Management Information System (PREMIS)

This system is a high level planning tool which utilises the critical path method through the precedence technique to represent the relationships between the activities that make up a project.

5.2 Outfit Material Control System (OMCS)

This is a system to control outfit materials, from requisitioning through to installation. It can be considered as a number of sub systems, covering requisitioning, purchasing, stock control, work packaging, marshalling.

The system also covers the production of requirements schedules for manufactured outfit items, related to planning unit stage and required date. The data is built up progressively as the design and planning become more detailed.

5.3 Steel Material Control System (SMCS)

This is a system to control steel materials from requisitioning through to installation. Its features are very similar to those of OMCS using the same database, enhanced with certain additional facilities related to structural steel.

5.4 Labour Cost Control System (LCCS)

The purpose of this system is to disseminate manhour target information to supervisors and managers and to provide reports comparing actual expenditure with targets.

Links within each work package to ship system codes, allow costs to be accumulated by ship system in addition to planning unit, to provide feedback to the estimating and costing departments.

5.5 Drawing Control System (DCS)

This system is used to assist in managing and controlling all drawings in preparation and current use, and to maintain records of drawings for ships in service.

5.6 Total Processing of Cables and Transactions (TOPCAT)

The TOPCAT system is concerned with the controlling of electrical cable stores, and tracking the progress of cable installation. It is also used to produce quality control and cable-testing schedules for attachment to test forms.

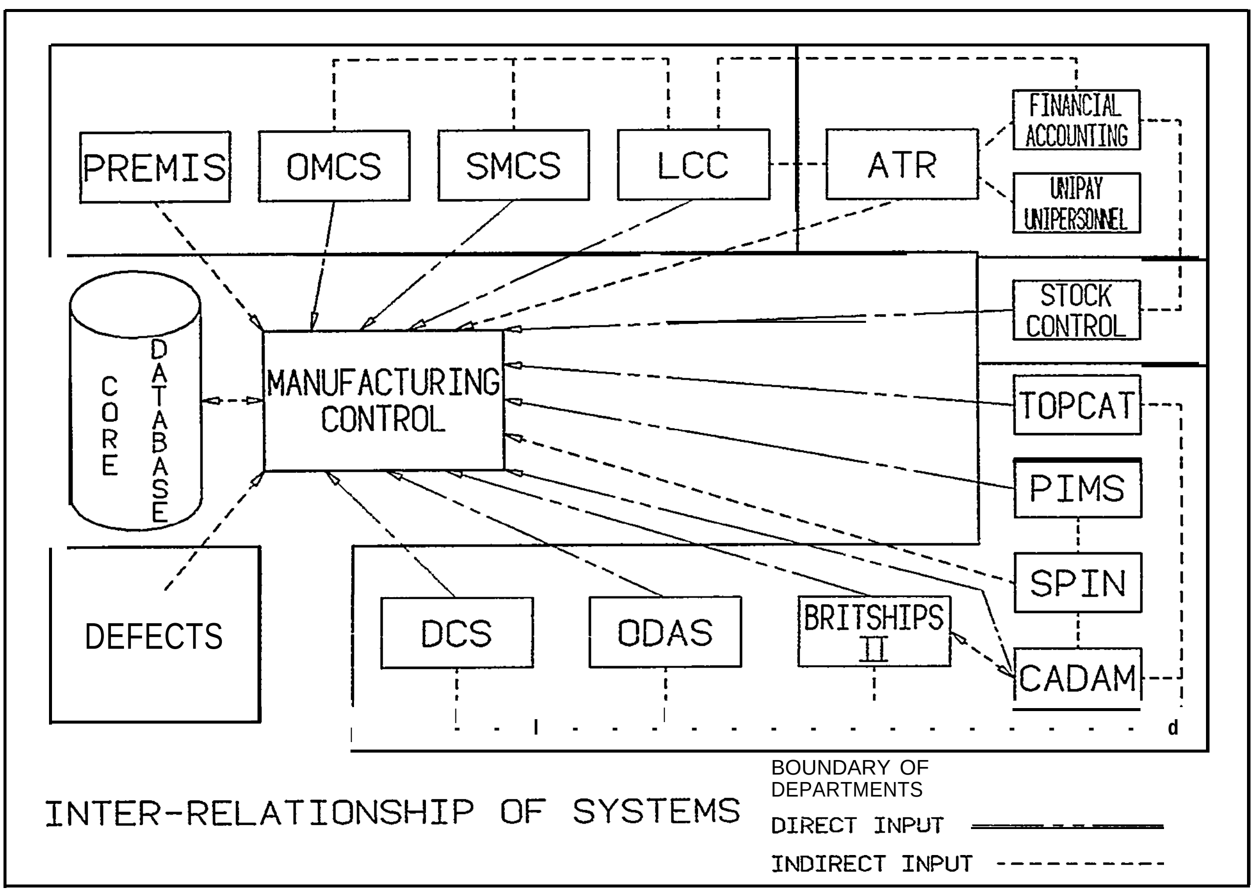

Figure 5 System Links

5.7 Pipe Information Monitoring System (PIMS)

This system controls the progress of the manufacture and installation of pipework. It enables the status of individual pipes to be monitored.

5.8 Shipbuilding Pipework Information System (SPIN)

This system facilitates the preparation of production information for pipework. From specification and geometric data fed into SPIN, pipe sketches are produced which include all material requirements and NC bending information necessary to manufacture the pipe.

5.9 Computer Augmented Design and Manufacture (CADAM)

This is a graphics software package which covers the draughting process from preliminary design through detail design to production information.

5.10 Automated Time Recording (ATR)

This is a system for registering time and attendance at work. The system registers manhours to individual employees, directly interfacing the Labour Cost Control System. Together these two systems provide an integrated job recording system which provides a high level of information to management. It is possible to interrogate the system to ascertain which employees allocated to a particular cost centre/work station are in attendance, within minutes of the start of a shift.

Every manual employee's manhours are recorded against a work station and a work package. The record of which individual's time has been recorded against any work package during the previous eight weeks can be extracted from the system.

At the beginning of each day production supervisors receive computer printouts which list all personnel who had been allocated to them on the previous day, and the work packages upon which they were working. If an individual is still working on the same work package then the supervisor need only sign the printout to register it as a repeat. However, if an individual begins to work on a different work package at the start of, or during, the day then the supervisor must enter the stopping time of the previous work package and the new work package number on the print out. The printouts are returned to the Payroll Department at the end of each day.

6. OPERATING EXPERIENCE

The system has now been operating for five years, and in that time coverage has expanded steadily to the point at which the construction of all vessels scheduled for completion from 1990 onwards is being controlled with the aid of the system.

Following a successful pilot scheme involving the work packaging of staff activities carried out, appropriately, within the Work Preparation Department, monitoring of staff expenditure related to specific work packages has been initiated on a major refit contract which commenced in the second half of 1989. Work packaging has also been successfully extended to the company's activities in the field of general engineering.

One of the system's major strengths, however, has been the ability to adopt a flexible approach with respect to the degree of utilisation on each contract. It is possible to tailor the level of definition required to suit the complexity and timing of any particular contract, and this facilitates a graduated application in which the service level can vary and be matched to the requirements of the project.

An early concern was that information to effectively budget small packages of work did not exist, and that this might cause significant problems in work package scheduling. However, the inherent ability of the system to provide very rapid feedback meant that this problem was rapidly overcome. Budgets for early work packages were established on the basis of overall work station performance figures adapted to the specific task in the work package by the judgement of the operations controllers, and within a very short period of time information on manhours expended on completed work packages became available to allow the operations controllers to refine the budgeting process.

In the early days of the system this refinement was an almost continuous process. However, as the operations controllers gained experience and sufficient information on actual performance was collected to enable stable performance rates for various tasks to be established, the accuracy of budgeting increased rapidly.

The overall extent of the improvement in budgeting accuracy and reporting discipline is illustrated in figures 6, 7 and 8, which show, for one work area (steel sub-assembly), the

reduction in variation in key work package scheduling parameters since use of the system commenced.

Once the initial period was passed and stability of performance measures was established it became possible to use those measures to set targets for subsequent work packages, which represented performance improvements in a step by step manner, in the knowledge that the improvements being sought were achievable. A major contribution to those performance improvements was the ability to use the system to accurately identify and cost non-value-added activities. Once the concerns identified in Section 3.2, relating to management scrutiny, had been overcome it became routine for foremen to request the operations controllers to raise extra work packages against which unplanned or nugatory work could be charged. The feedback from these work packages provided management with a powerful tool for the identification of areas where performance improvement initiatives would be most effective.

An example of the application of this approach is the selection of production-related re-work as an area for management attention. Figure 9 shows the distribution of total recorded manhour expenditure on all unplanned work, from whatever source, in the Block Construction Facility on the first merchant-type ship to which the system was applied. The proportion attributable to production-related re-work, entirely the responsibility of production management, was seen to be 48% of unplanned work. By reference to the descriptions of work packages raised to cover nugatory work it was possible to identify and investigate specific causes of re-work. Table II shows the reduction in production-related re-work costs on the second and third merchant-type vessels covered by the system, consequent upon management action initiated following investigation of the costs on the first ship. By way of comparison, figure 10 shows the distribution of unplanned work costs on the second ship.

The detailed definition of material requirements related to a specific task to be carried out within a known time window, has led to improvements in the process of material marshalling. As soon as the process engineers have released a work package to the system it is possible for the operations control staff to begin validation of material availability for that work package and, where appropriate, preparation of instructions to the stores organisation to release the necessary materials. This

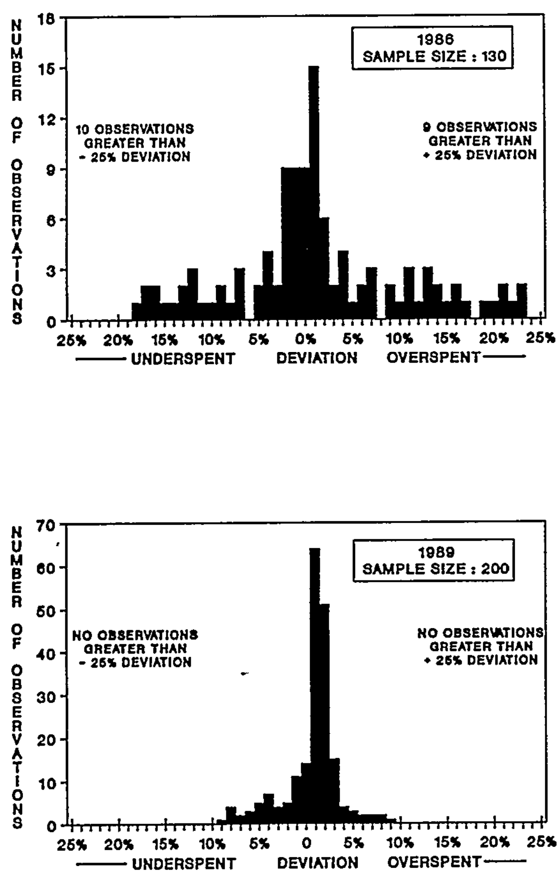

Figure 6 Deviation From Work Package Planned Hours : 1986 And 1989

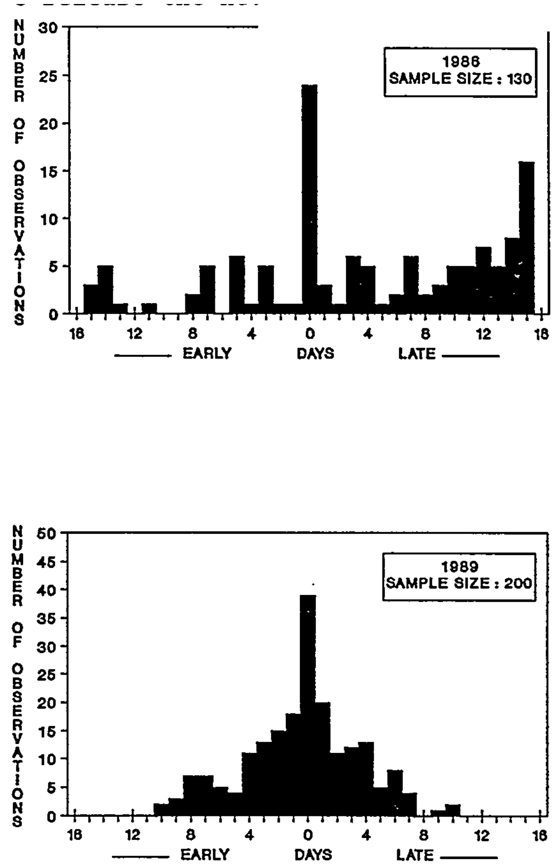

Figure 7 Deviation From Work Package Planned Finish Date : 1986 And 1989

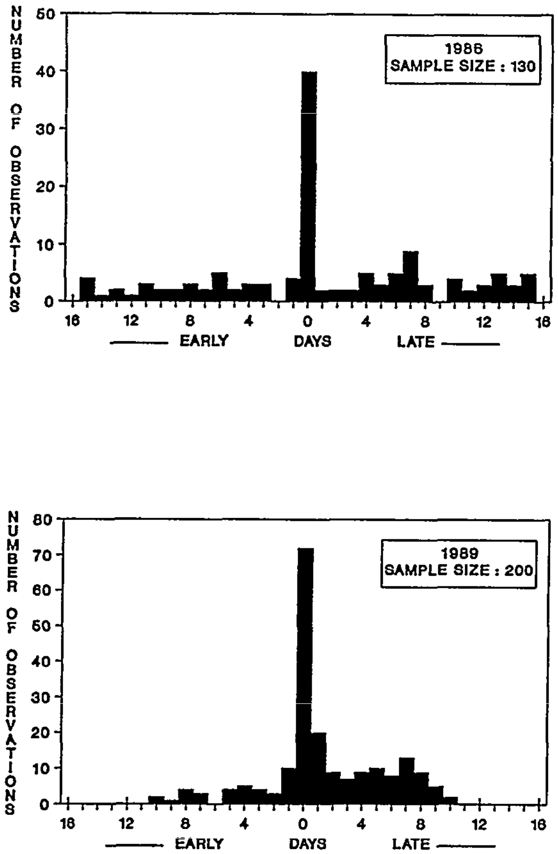

Figure 8 Deviation From Work Package Planned Start Date : 1986 And 1989

TABLE II: PRODUCTION RELATED RE-WORK COSTS (BLOCK CONSTRUCTION)

VESSEL	% TOTAL HOURS ON RE-WORK	COMMENTS
Ship 1	1.73	Completed ship
Ship 2	1.08	Completed ship
Ship 3	1.25*	At 52% complete

* Experience suggests that this figure will fall as the proportion of work completed rises and the most complex blocks are completed.

has had the effect of focusing the material control efforts of the operations controllers in line with the requirements of the short term schedule.

6.1 System Benefits

The benefits of the system have been evident in a number of areas and the following list identifies some of the most significant:

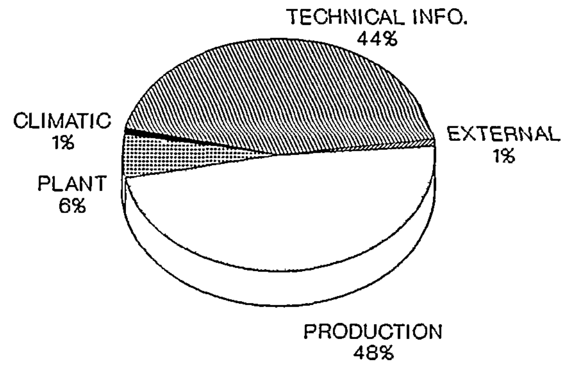

Figure 9 Unplanned Work Categorisation (Ship 1)

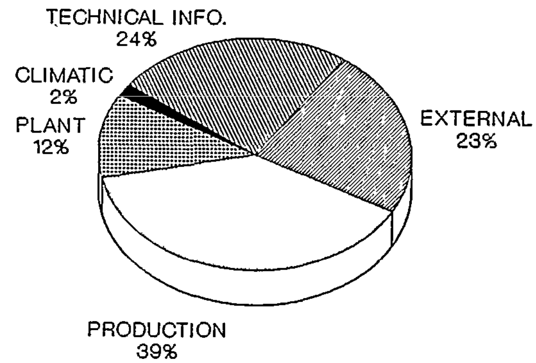

Figure 10 Unplanned Work Categorisation (Ship 2)

i) A significant contribution to overall productivity improvement. Figure 11 shows performance improvement at specific Block Construction work stations since use of the system commenced, and Figure 12 shows overall block construction performance improvement on successive ships. It should be noted that these improvements are the result of a series of initiatives of which task definition and work packaging form only a part. However, we believe that up to 50% of the total improvement can be attributed, directly or indirectly, to the use of the system.

ii) Scheduling of work and prediction of resource requirements are significantly improved (see figures 6, 7, 8).

iii) A more accurate understanding of completion status against manhour expenditure is achieved.

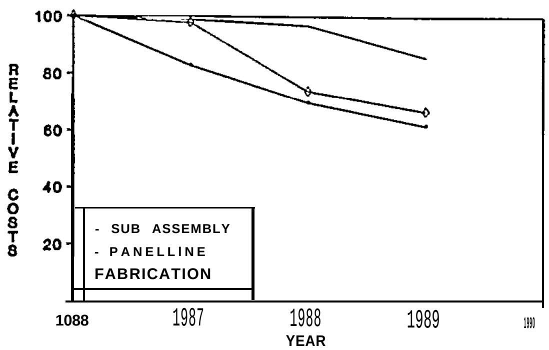

Figure 11 Block Construction Facility Performance By Work Area

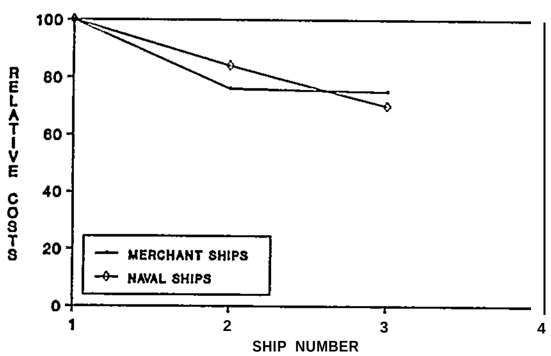

Figure 12 Block Construction Facility Performance By Ship

iv) Improved predictions of expenditure to completion can be made.

v) Greater accountability of management and supervision and improved awareness of resource utilisation, costs, performance and progress.

vi) Feedback of information which can be used for improved scheduling, production engineering decision making and ultimately improved estimating accuracy (see figure 6)

vii) Accurate costing of non-value-added activities and of rework (see figures 9,101.

viii) Accurate costing of modifications and changes.

ix) More effective validation of material availability to meet programme requirements.

6.2 System Constraints

To operate the system effectively certain costs and constraints are imposed upon the organisation.

An increase in pre-production lead time and manhour expenditure is required to enable the detailed task definition, materials allocation and scheduling activities to be carried out in a timely manner. This places great importance on the effectiveness of the company's pre-production planning activities and demands parallel working in the Design Engineering and Work Preparation areas to minimise the time required. During the preparation of the project plan (see Section 2.2) sufficient attention must be devoted to that part of the plan addressing design, procurement and scheduling.

Table III shows the cost of task definition and work packaging activities, expressed as a proportion of production manhours, for three recent vessels.

TABLE III: COST OF TASK DEFINITION

VESSEL	PROCESS ENGINEERING MANHOURS AS PERCENTAGE OF PRODUCTION HOURS		
	STEEL	OUTFIT	COMMENTS
A	1.3	2.6	Steel complete Outfit 85% complete
B	1.9		Steel only
C	1.4	3.4	Steel 80% complete Outfit 20% complete

As experience has been gained, the effectiveness of the process engineering function has increased, and this is illustrated in figure 13, which shows how the average cost of producing a work package for Block Construction steelwork has decreased over 3 ships, and the target cost for a current vessel.

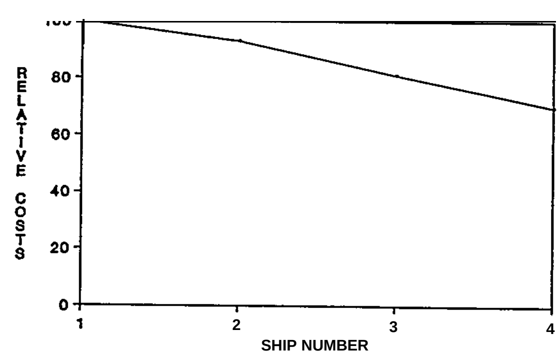

Figure 13 Work Preparation Performance (Steelwork)

The rigorous approach to task definition removes a large element of the "on the spot" discretion of production management and supervision related to where, when and how a job will be carried out. On occasions, this has resulted in concern, especially from users new to the system and unfamiliar with the degree of production participation in initial production engineering decision making which is inherent in the process.

A substantial majority of production activities carried out within the company are now covered by the system and it has generally been the case that those operating the system at all levels, from shop floor tradesmen to department management have rapidly overcome the teething troubles of the system and find it a straight-forward and effective system of planning and control.

7. FUTURE DEVELOPMENTS

During the five years in which the system has been in use significant benefits have been achieved. It is believed, however, that substantial further benefits can be achieved in the future as the system is further developed. Those areas which are now in steady state operation are being consolidated to provide a base for further expansion and some potential developments are listed below.

As the staff work packaging system becomes fully operational and is extended further along the pre-production chain it will be possible to accumulate cost information for planning units for every stage from functional design to testing and commissioning. This will provide a much needed database to facilitate accurate estimates of staff costs related to product characteristics. Preparatory work has commenced for the next major step, the extension of *work* packaging to cover design engineering activities on a first of class design, and implementation will commence on the next major first of class contract expected during 1990.

Further effort will be applied to the area of process definition both within and between work packages. Building on the work done in the area of steel fabrication and pipework installation, the next major step will be process definition for general outfit work packages. In addition, further definition of work package interdependencies will be developed as an aid to scheduling. As a first step in this process, testing has commenced of a mechanism within the system which prohibits the scheduling and opening of any assembly work package for which component manufacture is not complete. This mechanism is based on the development of automatic links between the manufacturing work package required for the production of any component and the subsequent assembly work package requiring the use of that component.

Feedback from the system to date has been largely used to improve budgeting and short term scheduling activities. As the range of application increases and the store of information grows it will become valuable base data for both the production engineering function and, in the medium term, the estimating function.

Analysis of re-work costs in conjunction with related quality information derived from the company's total quality system will allow confirmation of the validity of production tolerances and identification of those areas where process revision is required.

8. CONCLUSIONS

Although not without its teething problems, experience with the system over the past five years of increasing application has led to a general belief that the benefits of the system fully justify the cost and effort required to set it up. Substantial benefits of increased management control and accountability and major contributions to productivity improvement have already been achieved. As shown in Table III, the additional incremental cost of operating the system has been less than 4% of total production manhours and, as can be *seen* from figures 11 and 12, the total improvement in performance during the time in which the system has been in use, and to which the authors believe the system has made a major contribution, is substantially more than this incremental cost. The operation of the system has developed rapidly, leading to decreases in its operating costs and, as the potential of the system in the fields of process definition and engineering feedback is exploited, substantial further benefits are anticipated.

9. ACKNOWLEDGEMENTS

The Authors have based this paper on their work at Swan Hunter over the last few years and they are grateful for the support of the company and for permission to publish the paper. The opinions expressed, however, are entirely those of the authors, who wish also to acknowledge the contributions of their colleagues to the work described.

10. GLOSSARY

ATR	Automated time recording.
CADAM	Computer augmented design and manufacture.
DCS	Drawing control system.
LCCS	Labour cost control system.
MLF	Material list by fitting.
NC	Numerical control.
OMCS	Outfit material control system.
PIMS	Pipework information monitoring system.
PREMIS	Project Resource Evaluation Management Information System.
SMCS	Steel material control system.
SPIN	Shipbuilding pipework information system.
TOPCAT	Total processing of cables and transactions.

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24,1990

TQM For Survival

2B-l

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ABSTRACT

Naval shipyards face a declining workload in the nineties and beyond. Survival is a key issue. Total quality management (TQM) is one of the keys to survival. Being the best performer by focusing on customers' ever-demanding needs is the bottom line.

Portsmouth Naval Shipyard has developed a TQM effort that will allow us to improve performance, communicate more clearly, and focus on customer demands. Our TQM model requires committed leaders, involves training for everyone, and calls for the building of teams to break down the functional barriers. It includes teams making incremental improvements in all of their work processes and dramatic improvements in the vital few work processes. It also listens to the voice of the customer.

TQM is a long-term system of improvement; however, some results are already evident from working in this new way:

- Pipe weld radiography technique rejects have been cut in half.
- Shipboard power distribution testing has been improved by 600%.
- Material inventory in one area has been reduced by $5 million with no effect on customer service.
- Savings of $1.4 million per year resulted from eliminating unnecessary technical instructions.
- Savings of $61,500 resulted from applying the lessons learned from ship to ship on a new systems installation.
- Savings of $1.3 million per ship resulted from improving the work processes on applying a special hull treatment system.

TQM FOR SURVIVAL

Why TQM? Portsmouth Naval Shipyard is one of eight naval shipyards. All are involved in surface ship or submarine repair and overhaul. Our work involves only nuclear submarines. Portsmouth currently has about 8300 employees. We are the primary employer in our area; hence, many communities in Southern Maine and New Hampshire depend on our jobs. The yard has an economic impact in this seacoast region of three quarters of a billion dollars. The outlook for the next ten years can be seen from Figure 1.

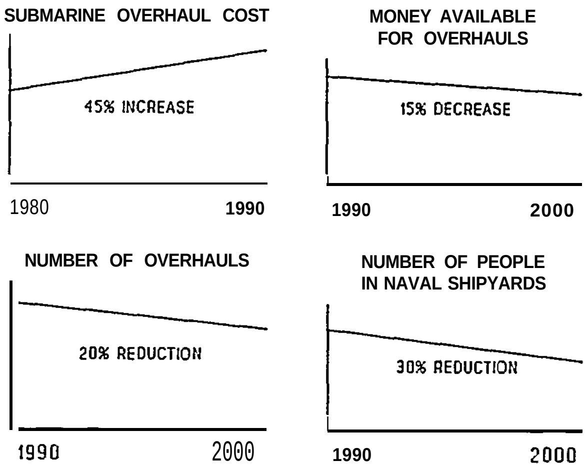


Figure 1

This makes the question "Why TQM?" an important one for this shipyard.

The answer is obvious: long-term survival. Survival in a changing world is not unique to shipyards. The automotive and consumer electronics industries are certainly good examples of survival and a changing world, and what can go wrong.

What's ahead?

John F. Welch, Jr., CEO of General Electric, sums it up very nicely: "Simply doing more of what worked in the

eighties . . . will be too incremental. More than that, it will be too slow. The winners of the nineties will be those who can develop a culture that allows them to move faster, communicate more clearly, and involve everyone in a focused effort to serve ever more demanding customers. To move toward that winning culture we've got to create a 'boundaryless' company. We no longer have the time to climb over barriers between functions like engineering and marketing, or between people-hourly, salaried, management, and the like."[1]

How does this fit with long-term survival and TQM? TQM is a major part of the cultural change we are trying to make to better serve our customers. Our TQM effort is customer focused. It involves teams to allow us to move faster, communicate more clearly, and break down the barriers between functions and people. TQM is not something in addition to what we already do. It is not another program for management to administer. It is the new way we will we operate-a never-ending journey of process improvement involving everyone.

Lessons Learned

When we went through the quality circle and improvement team cycles in the past, we learned some valuable lessons for quality improvement:

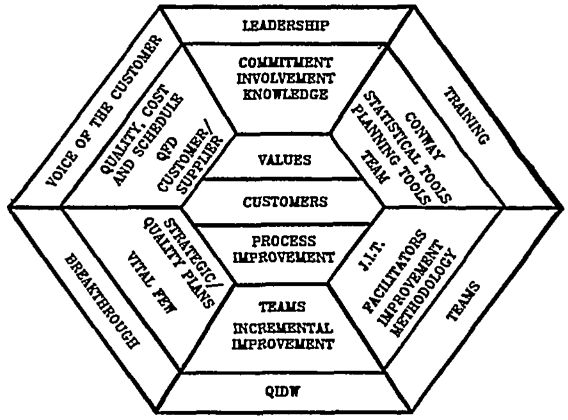
- top leader commitment is absolutely critical;
- you must have a clear focus on <u>process</u> improvement in the organization:
- everyone must be involved, starting at the top.

Accordingly, we sought to employ these lessons learned in building our present improvement effort.

TQM MODEL

In the last two and a half years we have developed a TQM model (figure 2) that will help us see the huge and rapid changes that lie ahead as opportunities rather than as threats. Our model centers on customers, values, and process improvement. The model represents how we have developed and will continue to develop our TQM effort.

The model starts with leadership at the top. our first effort was to build a core of top leaders who were committed to lead the TQM effort. They had to get involved to show what had to be done. (People watch your feet, not your lips.)



PORTS MOUTH TQM MODEL

Figure 2

The knowledge required came through training, the next part of the model, which started with William E. ConWay's course, <u>The Right Way to Man-</u> - . Much of our TQM effort is based on his concepts. Training also includes the statistical charting tools, the planning tools, and how to function in teams.

Teams, the third part of the model, are the basic way we will operate in the future. They are the technique that best allows:

- clearer communication;
- more rapid response;
- breaking down the functional and people barriers;
- tapping the vast potential of our people.

our experiences show that teams must be supported by facilitators and just-in-time training in group dynamics and statistical charting tools and techniques. An improvement methodology serves two important purposes: (1) to keep teams focused on process improvement, not just problem solving; (2) to create a common language to more clearly communicate improvement.

The next part of the model, quality in daily work (QIDW), involves the teams in action, working on maintaining or incrementally improving the work processes. Day-to-day work is managed by facts. Statistical tools are used to reduce the variation in the work processes.

[1]"Today's Leaders Look to Tomorrow," <u>Fortune,</u> 26 March 1990, p. 30.

[2]Produced by Conway Quality, Inc., Nashua NH.

Breakthrough is a key part of the model, since it involves meshing our strategic business plan with our Quality planning to determine which "vital few" objectives will get a large focus of resources and efforts to make dramatic improvements in the key work processes related to those objectives.

The final part of our TQM model, the voice of the customer, is mostly in the conceptual stage. Again, we will use teams-most likely cross-functional-to optimize the management of Quality, cost, and schedule at the shipyard level. In this part of our TQM model we want to build a system where every person knows their customer's expectations and is working to meet those expectations and create new ones.

PROGRESS IN IMPLEMENTING THE TQM MODEL

We began implementing each part of the TQM model as it was being developed. Our progress can be seen in the following overview of each part:

Leadership,

- All the top and mid-level leaders in the shipyard have been trained in the basic concepts of TQM.
- Each of the top 30 leaders has finished leading at least one team through at least one improvement project.
- Approximately 30% of the leaders are committed to TQM.

Training

- Approximately 60% of the shipyard population has had TQM awareness training in the Conway concepts.
- Statistical tools training and team training are working well.

Teams

The just-in-time training of teams is very effective because training is delivered when the need to learn is highest.

More facilitators are being developed to meet the expanding needs of a growing number of teams.

- Our improvement methodology keeps teams focused on process improvement. It also helps build a common language for process improvement.

Quality in Daily Work

Over 300 teams have been formed to work on improving daily work processes.

Breakthrough

- The 30 top leaders have been trained in quality planning tools. They have developed a strategic business/quality plan that includes a mission, a vision, and objectives that focus our TQM efforts on the vital few issues.

Deployment of the strategic business/quality plan is under way.

Several top leader teams are working on major shipyard systems that will enable us to meet our vital few objectives.

Voice of the Customer

- Customer-supplier training has been developed and shown to be effective in a few areas.
- Key top leaders are being trained in quality function deployment to better understand how this tool can be used to support this part of the model.

CHALLENGES AND OPPORTUNITIES

There are at least five key challenges and opportunities in implementing our TQM effort.

1. We must continue to build the core of top leaders who are fully committed to TQM. We believe there are four possible barriers to top leader commitment.

   a. Leaders feel that being committed to TQM is not clearly in their best interest. (Promotions, awards, and recognition are still being given to leaders who are not involved in TQM.)

   b. They are not empowered with authority and resources.

   c. They don't understand how to implement TQM.

   d. They choose not to be committed to TQM.

These four opportunities for improving commitment will be pursued through continuing TQM education and through collecting data to identify which barriers apply to whom and then acting on the data.

2. Deploying our mission and vision (the strategic business/ quality plan) throughout the shipyard and accomplishing the one- to two-year objectives that support our mission and vision are clearly an opportunity to work on the breakthrough part of our TQM model. These tasks also provide an additional opportunity to get top leader commitment and involvement.

3. A challenge for both management and the unions is to be full partners in the TQM process. In the future struggle for survival there will be little room for the waste that results from barriers between management and the unions. Both must move toward the middle to become partners in the TQM process if we want to use all of our efforts to survive in the competitive and changing world.

4. Another serious challenge is changing our basic systems and methods to allow everyone to think, work, and act according to our values. These values-excellence, treatment of people, teamwork, satisfying the customer, and continuous improvement-must be woven into every decision, every act, and every thought-by everyone. This is the culture that John Welch talked about in the Fortune article. These basic systems and methods, if not aligned with TQM, are as Welch says, "the barriers to clear communication, improvement, and teamwork."

5. The final opportunity is to develop the voice of the customer to complete our TQM model.

RESULTS

The results of our TQM effort that can be measured at this time come mainly from the QIDW teams working on process improvement. Major improvements in processes will occur as we make breakthroughs. These breakthroughs and the improvements resulting from changes in our basic systems and methods (those affecting our values) will bring the greatest dollar savings. We are almost at this point in our TQM effort.

Listed below are six examples of process improvements involving QIDW teams from quality assurance, engineering, supply, and production. These examples also represent a cross-section of leaders from first-line supervisor to department head.

Radiographic Technique Rejects

The team that worked on improving the radiography process included the department head, all levels of supervisors, and workers.

Radiographic technique rejects increase costs and cause delays. The Pareto chart in figure 3 identifies sensitivity as the major cause of such rejects. It shows that the number of

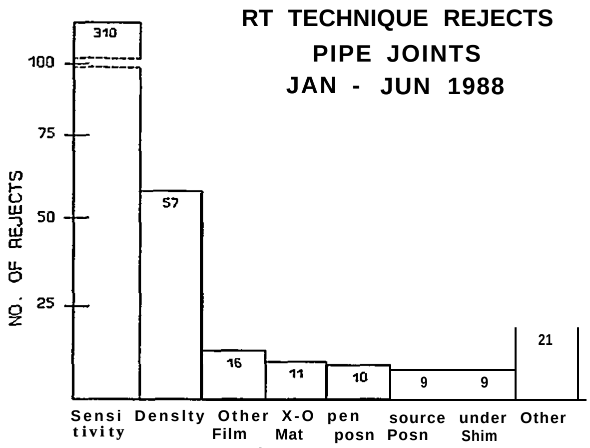


Figure 3

sensitivity defects was five times as high as the second main cause of rejects. All of the following processes that could affect sensitivity defects were studied by flow charts and cause-and-effect analysis:

setting up and taking the shot;

selecting the type of film;

processing the film;

interpreting the results.

Variation in these processes was reduced by making the radiographers aware of the variation and its effect on sensitivity. One change in the process was implemented after cause-and-effect analysis showed it could be a major contributor. The results are shown on the control chart in figure 4.

The plot on the left shows the process before the study was undertaken. The process had wide variation and a 21% average reject rate. The plot in

the middle shows that the variation was reduced and the average reject level was down to 14%. This resulted from studying the work processes and making the radiographers aware of the variation in the processes they used. The plot on the right shows the process after making a process change. The average reject rate is down to 10%. However, the variation needs work. One month was out of control due to a special cause-several pipe joints with configurations that were difficult to radiograph.

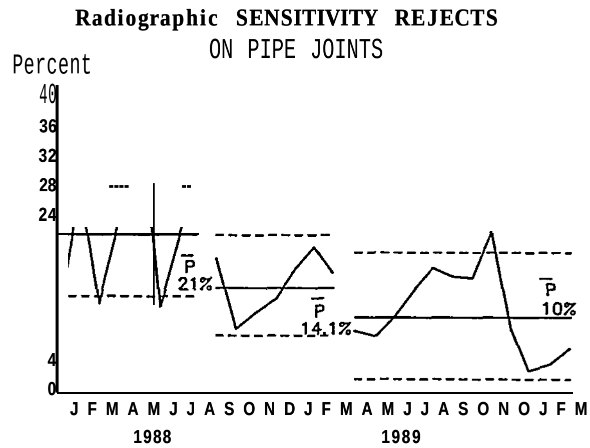


Figure 4

Shipboard Power Distribution Testing

The production people who worked on shipboard power distribution testing felt there were many forms of waste in the testing process, so they formed a team with the engineering people to eliminate the waste. The team identified a number of sources of waste by brainstorming and then fixed the identified problems. Brainstorming showed the process contained:

- redundant and unnecessary steps:
- inefficient sequencing of operations;
- excessive changes in test procedures;
- delays in processing test procedure changes:
- too many verification points.

The savings in time and elimination of problems can be seen in figure 5. As the number of instruction changes was reduced to one, the delays in processing changes were eliminated.

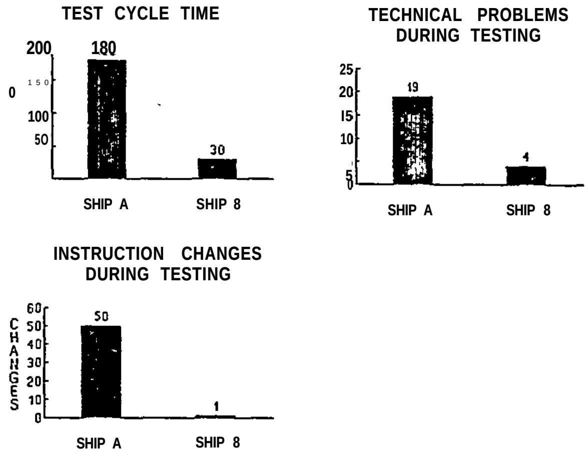


Figure 5

Excess Material in Inventorv

A team consisting of the department head and several levels of supervision identified excess material in our shop stores as a source of waste. Shop stores materials are consumables that are low cost, fast moving, and issued near the work sites.

The team's project involved flow charting the processes to see how they could be improved. The team was particularly interested in determining if there was a clear line of responsibility for controlling excess inventory. They also used Pareto charts to identify the best shop stores issue stations and then used those as models for improving the others. The results of their efforts are shown in the two run charts, figures 6 and 7. Material inventory was reduced by almost $5 million without impacting customer service. Unsatisfied customer demands remained around 3% while the volume of business remained steady.

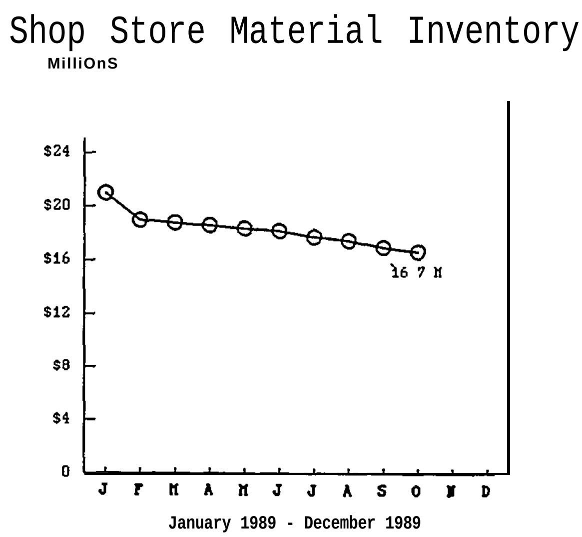
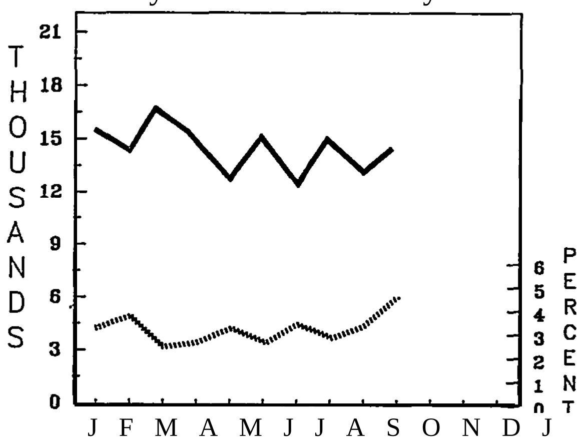


Figure 6

Shop Store Materlal Issues

January 1989 - January 1990



- Customer demands

.=-... Unsatisfied demands

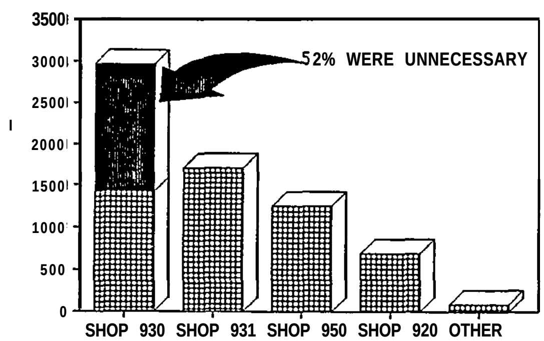
Figure 7

Unnecessary Technical Instructions

People in the engineering division believed they were writing many unnecessary technical instructions. They formed a team with supervisors from one of the production shops to identify and eliminate the waste in the system used to resolve technical problems encountered at the work sites.

There are two ways for the workers or foremen to resolve these problems: either orally or by written request. Oral resolution is used when the problem is simple and requires no record of change. Written requests are used for all other cases. The cost of a written request ranges from $500-$900.

UNNECESSARY TECHNICAL INSTRUCTIONS GENERATED



SAVINGS OF $1,379,000/YEAR

Figure 8

When the team collected the data from the shop with the most requests, they saw that many requests that could have been resolved by phone calls were written. They also found that material problems were being resolved by written request. Most material problems can be resolved on the phone.

The team used flow charts and training bulletins to educate the workers and leaders in that shop. Figure 8 shows the savings per year that will be realized when the system is fully implemented in this shop. The team is working with a second shop to identify unnecessary instructions and to ultimately eliminate them in that shop.

Lessons Learned But Not Applied

A team of engineers, their supervisors, and production supervisors felt there was waste in repeatedly fixing the same problems from ship to ship. Typically, lessons learned on one ship are not always effectively implemented on the next, especially where new systems are involved.

The team focused on problems encountered in installing a new shipboard electronics system. They started by flow charting the process from planning to installation and testing, looking for waste and redundancy. Next, they categorized the problems that required technical resolution on the previous ship. Figure 9 shows the results.

PROBLEMS REQUIRING TECHNICAL RESOLUTION

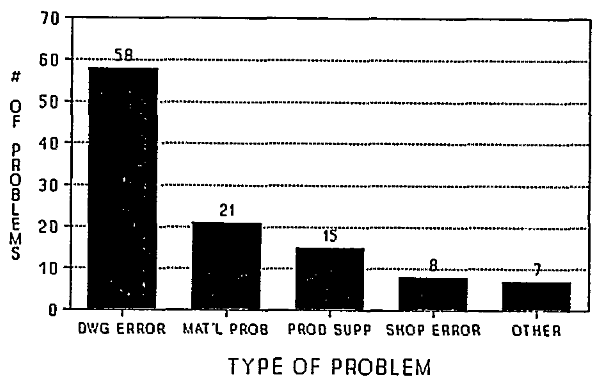


Figure 9

The root causes of those problems were eliminated. The teams then measured how well they were doing by counting the number of technical instructions generated at various phases of the work and comparing the number with those on the previous ship. A cost comparison was then developed, based on the average cost to generate a techni-

cal instruction (figure 10). Rework cost savings were not included, so cost savings are very conservative.

COST COMPARISON APPLYING LESSONS LEARNED FROM SHIP TO SHIP

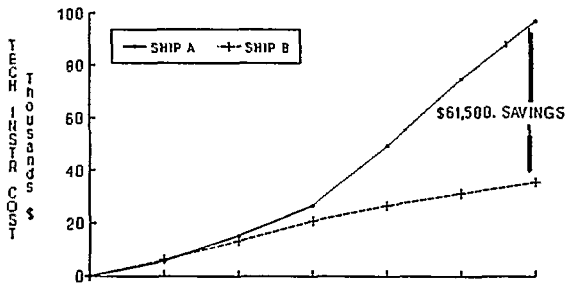


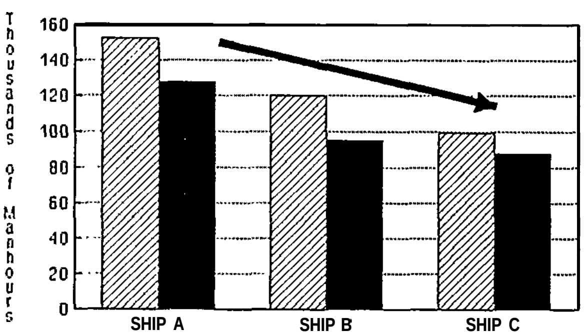
Figure 10

Special Hull Treatment Process

Special hull treatment is applied to most submarines during overhaul. The engineering and production people who design, plan, and install it decided there were many forms of waste in the whole process, so they formed a team to improve it. The team flow charted all of the work processes and collected data on what worked well on previous ships. From the flow charts and data analysis they:

- developed a more efficient installation technique;
- changed the work sequence in a major operation;
- improved the blasting and painting process;

SPECIAL HULL TREATMENT



SAVINGS OF $1,306,600,

Figure 11

- used a different configuration of work enclosures;
- developed a plan to more effectively use experienced people.

These actions resulted in the savings shown in figure 11 over three ships.

SUMMARY

Implementation of TQM is under way at this shipyard. We have a model that brings all of the elements together to focus on values, customers, and *process improvement*.

Values are the foundation for the way we will run our business. They are the goals of the cultural change we must make to foster TQM throughout our organization.

Customers--'internal and external-are the reasons why we provide products and services. No customers, no jobs! Obviously customers must be the center focus.

Process improvement is the way we use TQM to become more competitive. Improvements are normally made through teams of workers and supervisors. Teams break down functional and people barriers, promote clear communication, and allow people to reach their full potential. Teams must be empowered to be effective.

Savings are already evident. The greatest savings are on the horizon as we move into our breakthrough efforts, focusing on big improvements in the vital few areas.

TQM is the opportunity for survival. It's not an easy effort because it represents a huge change. Change is usually a struggle. Using change as an opportunity, we expect to ride on the TQM wave into the future.

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Paper presented at the NSRP 1990 Ship Production Symposium,
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Financial Questions-Industrial Engineering Answers

2B-2

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ABSTRACT

In quest of increased efficiency to make better use of financial resources, industry, both public and private sector, have often been turning to the industrial engineering community for help. And while there has been progress in measuring the efficiency of human resources and establishing work standards, similar efforts in the use of equipment have, in recent years, become of greater interest and will continue to do so in the coming *years.*

While tracking equipment utilization for a special study of a shop. process, or organization can be helpful, an ongoing program that is a part of routine management can more than pay for itself. Tracking equipment utilization can contribute to:

- Workload planning
- Evaluating equipment needs
- Identifying bottlenecks
- Identifying equipment with excessive down-time
- Identifying capability related to new opportunities
- Identifying needed equipment
- Equipment replacement decisions

Good financial decisions in these areas require a knowledge of current and past equipment utilization. Without valid information, an important ingredient of the decision process is missing.

There are many techniques for obtaining equipment utilization information. There are also several factors affecting the cost and validity of the data. such as continuity, time to set-up, cost to implement, cost to maintain, accuracy, and objectivity of the data. The various techniques and factors outlined are discussed and evaluated.

INTRODUCTION

The cost of fixed assets are a common area *of* concern to both private and public industrial organizations in that they affect the relative competitive position of the organization's activity. While there is a national rationale for minimizing equipment costs--i.e.. our national needs exceed our resources--there is an even more visible rationale for maximizing the return of these costs at an individual shipyard. In an increasingly competitive environment, notwithstanding the certainty of decreasing defense budgets, it is important that every available cost control tool be used. The primary

means of reducing costs include maintenance and analysis of equipment utilization data.

There are basically five steps in the economic analysis function:

Problem Identification

Measure (collect data)

Analyze

Verify Problem

Solve Problem

Collecting equipment utilization data 18 simply the measurement function.

INDUSTRY USES OF EQUIPMENT UTILIZATION DATA

Equipment utilization information is used widely in industry as a valuable tool to manage operations, control costs, maximize the return on investments and prepare documentation to verify need and audit the effectiveness of previous acquisitions. Virtually every company has more rigorous criteria and tightened controls over capital expenditures in recent years. In the airline industry new procurements are justified based on equipment utilization data.

The interest in equipment utilization often arises from a need to maximize the return on investment capital by optimizing the utilization of existing equipment and avoiding unnecessary expenditures for new equipment. Airlines send their wide body landing gear cylinders to a vendor for rework. Purchasing larger, specialized equipment would have very low utilization due to the low volume of this type of work.

Until recently. the primary focus of industrial engineers has been to reduce direct labor costs. As a result, there has been a marked reduction in direct labor costs relative to equipment and material costs. (Faster more efficient machines replacing more than one of their older, inefficient counterparts reducing required manpower and excess material costs). Although these efforts are not going to be abandoned, industrial engineers are increasingly being directed to improve the utilization of productive equipment.

MANAGE OPERATIONS

Equipment utilization data can aide in the management of industrial operations.

A major airline routinely assesses the capacity of its machinery in the shop. The methodology evaluates capacity-related information for each sub-shop by engine type. Data for each sub-shop is plotted on a chart, graphically portraying the overall workload and also highlighting those machines approaching capacity. When additional workload 18 anticipated, the required machine hours are computed and added to the current utilization data. This will help determine if the current machine capacity is sufficient to handle the additional workload.

Accurate forecasts (short. intermediate. or long-range) of workload, capacity, capital requirements, and operational needs are not possible without knowing current capabilities.

When volume increases to near capacity, or when a new product is being considered, one of the first questions asked is, 'Can we produce the work with the existing equipment?'

An organization must be able to accurately assess its ability to take on a new workload prior to committing to it by evaluating equipment needs. If the new workload exceeds the maximum capacity of an expensive piece of equipment, or equipment with long lead times to acquire, the shops' ability to meet commitments can be jeopardized.

At the shipyard a newly identified mission will over extend the capacity of the 5-axis profiling machines used for propellers. The first thought was to purchase a new B-axis machine, this would entail a three year lead time from purchase request to operation and over six million dollars. Utilization data was gathered for large milling type machines in the shipyard. The data showed that the 5-axis machines have a high utilization with no idle time and some down time (maintenance). The data gathered from the machine shop showed there are several large milling machines with very little utilization. After investigating the physical attributes (table size, feeds and speeds) it was decided that work not requiring 5-axis machining could be shifted from the 5-axis machines to the older manual 3-axis milling machines. This would allow

the 5-axis machines to work more efficiently with an increased capacity, doing the type of work they are meant to do and also increase the machine utilization and productivity of the machine shop. The new mission has still identified the need for new machinery. Some of the required work that would have to be accomplished using the 5-axis machines would once again exceed their capacity and make their production less than efficient. This would adversely affect completion dates. The purchase of a 2-spindle, Q-axis machine is being considered. This additional work will be done with accelerated productivity. The end results being increased shipyard productivity, increased machine utilization, Increased machine efficiency, and the accomplishment of a new mission on schedule.

If existing equipment cannot functionally handle the new work and new equipment with greater capability is required, it is often more economical to sub-contract the work than to do it in-house.

Some equipment may stand idle, along with the operators, even though there is work to be done. This happens frequently where the normal flow of parts has been interrupted causing production bottlenecks. Period-to-period variances of utilization data can point this out as a first step in identifying a problem area.

Equipment utilization data can point out which equipment has excessive down-time and could lead to improved maintenance practices or replacement, if practical.

When the shipyard was awarded the aircraft carrier life extension program, the new workload required a machine capable of drilling 2-l/2 inch holes. The plan was to use a one-of-a-kind early generation numerical control machine to support the new workload. Utilization data showed the machine had excessive down-time. Examination of the maintenance records showed the machine was over 15 years old and it no longer had the physical ability to produce the required work on schedule. With the help of this information it was decided to purchase a replacement machine. The new machine easily handles the workload it an increased productivity level.

Preventive maintenance is generally most effective if it can be tied directly to actual utilization, as opposed to a specific period of time.

CONTROL COSTS

The economic environment of business has changed significantly over the past two decades. A business cannot survive unless it is cost- competitive. Many private firms with excess capacity and the necessary capability are competing with or replacing public sector functions.

Equipment utilization data will aid in making economical and logical source decisions.

If existing equipment does not have the capacity available to handle contemplated work, it is often more economical to farm the work out to other vendors. Performing an economic analysis can help decide whether to add capacity, run a third shift or work overtime. Very often, when workload increases, the best alternative to purchasing new equipment is to add a shift or to work overtime. If the added work is of short duration, it is seldom economical to buy new equipment. If the work is long-term, then equipment utilization data is valuable for conducting least-cost studies of the alternatives.

Costs can also be controlled by removing unneeded equipment by reducing space, maintenance and power requirements.

MAXIMIZE RETURN ON INVESTMENTS

Is replacing existing equipment an essential or operational requirement; if not, is there an economic justification?

Can current utilization be increased? Can productivity be increased? Can replacement be avoided? A major auto manufacturer developed a company-wide machine utilization program which has increased machine productivity. All of the remote plants use the same method to determine and measure equipment utilization. This measurement system is primarily applicable to mass production operations in which equipment utilization for many machines is nearing capacity and a slight increase in workload causes major production problems. At the same time, because many machines are near maximum capacity, any successful efforts to improve equipment

productivity generally result in the avoidance of capital expenditures.

EQUIPMENT UTILIZATION MEASUREMENT TECHNIQUES

The techniques used to collect equipment utilization data vary widely, depending on the following factors.

Continuity of data - For job shop operations, with large fluctuations in workload, a continuous method provides better data.

Time to set up - Some data collection techniques need long lead times to install due to the amount of resources, planning, and systems work required.

Cost to implement - Techniques involving computer systems and timers require higher expenditures to initiate.

Cost to maintain - On going, day-to-day costs to collect and manage equipment utilization data vary by technique. Automatic log-on/log-off and estimating systems are comparatively inexpensive.

Accuracy of data - Some applications, such as a cost benefit analyses, require very accurate data, while others need only ballpark figures.

Objectivity of data - Techniques which provide reproducible, verifiable data and which obtain data in the most objective manner will stand up better under third party audits.

Usefulness of data - Related to accuracy and objectivity, to be useful, the data must have credibility.

There are five primary measurement techniques for measuring equipment utilization.

Automatic log-on/log-off system - The automatic log-on, log-off system of data collection enables the equipment operator to log-on and start data collection at the start of a job then log- off and stop data collection when the job is completed. Log-on/log-off can be accomplished by direct entry to a computer via a punched card, keyboard, or bar code reader. The computer maintains utilization data as well as other job-related information. This information is available for various analyses. This technique provides accurate, objective data; however, it takes a long time to develop and install, and a large computer systems effort is required.

Sampling - Work sampling provides accurate information in proportion to the number of samples taken and, therefore, to the amount of labor required to collect it. Sampling also requires the observations to taken at a randomly selected time, and the particular 'labor state' being observed to be accurately defined and properly recorded. In equipment utilization the interest is in studying the 'machine' or 'equipment state' in the same manner as work sampling.

Spindle recorders - Spindle recorders can provide accurate data for some machines if the time measures more than just motor time. For example, a *sensor* attached to a spindle of a lathe, or the work-producing, moving part of the machine, will provide the time the spindle is active, but not setup, teardown, or miscellaneous times.

Operator logs - Logs provide fair data, at a relatively low cost, if the procedure to record the data is consistently applied.

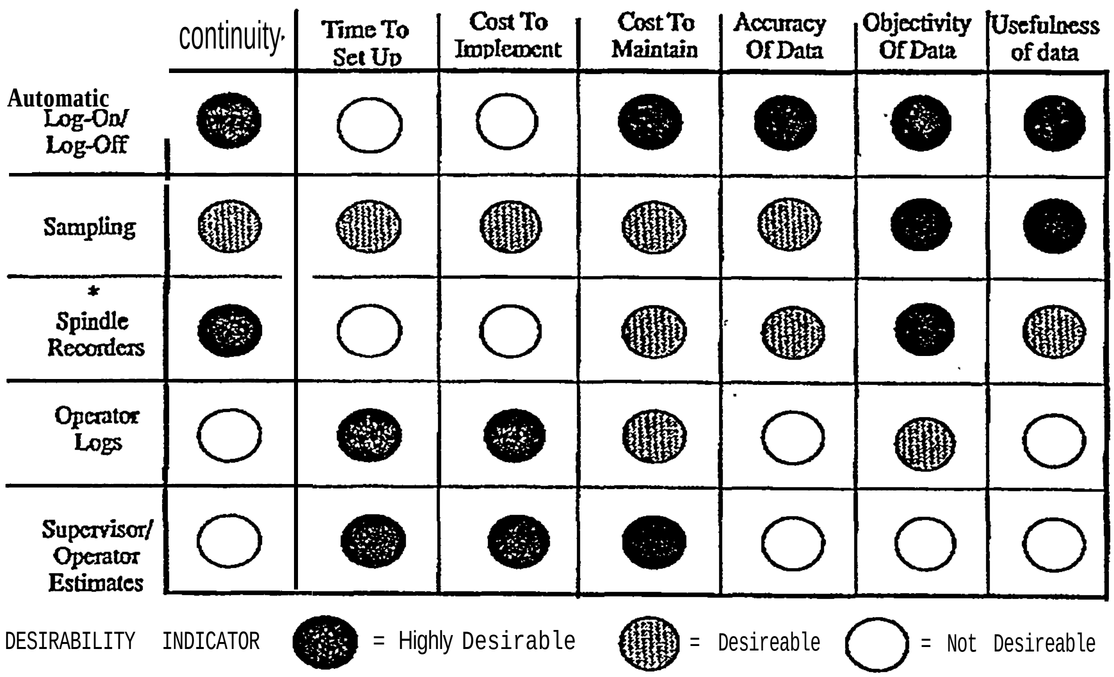
Supervisor/Operator estimates - This method is used for filling in gaps in existing data, or for isolating problem areas or bottlenecks. Data tends to be overstated because memory tends to focus on the 'worst case.'

EVALUATION OF TECHNIQUES FOR OBTAINING EQUIPMENT UTILIZATION DATA

The particular equipment utilization technique adopted depends on a trade-off of the various factors affecting the cost, validity, and priority of need for the information. Figure 1 shows the relationship of the factors affecting all the data collection techniques by rating the important factors relevant to data collection from highly desirable to undesirable.. While the chart is based primarily upon the observations and experience of several industrial engineers, as opposed to any empirical data, it is the judgement of these professional engineers that the data presented is reasonably accurate for the management process of deciding which techniques to use. While automated log-on/log-off techniques can be extremely accurate,

there are problems associated with relating the usage to production: there is also a significant cost factor. Sampling is in the middle ground of cost and extremely accurate, if the program is run with integrity and a good data base is maintained.

EVALUATION OF EQUIPMENT UTILIZATION TECHNIQUES



*** ASSUMES NO CURRENT CAPABILITY**

Figure.1

SUMMARY

Establishing a data base for maintaining equipment utilization data will significantly contribute to the confidence level in proposed procurements of plant property equipment, whether for replacement, enhancement, or upgrade. It will also allow the user to take advantage of lessons learned and to optimize the use of resources. An equipment utilization program should enable the user to avoid equipment replacement when possible and make smart procurement decisions when necessary.

ACKNOWLEDGEMENTS:

Walter Hemphill, Carl Olson and James Miller: Philadelphia Naval Shipyard, Code 380

Phillip Johnson, William McCune, John Crotty, Ira Grossman. and Chris Dolman; Booz. Allen, Hamilton Inc.

Wallace Bateman, John Wilson, and Joseph Gaudet; Science Management Corporation

Lynn Waite; American Management Systems Inc.

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601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24, 1990

Advanced Industrial Measurement Systems for Productive Shipbuilding

3A-1

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ABSTRACT

Modern shipbuilders have embraced the concept of modular construction and are realizing the gains in productivity associated with these methods. Further gains in productivity are achieved if these modules are built and erected "neat," that is, without the traditional excess material normally trimmed at erection. Construction of "neat" hull blocks requires rigid control of accuracy throughout the production cycle. Interim products, from fabricated parts to erected hull blocks, must be measured to acceptable tolerances to prevent excessive rework.

The object of this paper is to analyze viable types of advanced measurement techniques supporting the process requirements of "neat" modular construction. Documentation of costs and difficulties associated with each measurement technique selected are also analyzed.

The first part of the paper is a general description and analysis of the systems. The second part describes actual demonstrations of three measurement systems and analyzes them in the shipbuilding environment. Demonstrations of digital theodolites, automated photogrammetry and an optical laser system are described and analyzed.

INTRODUCTION

This paper is a synopsis of an NSRP project "Advanced Measurement Techniques for U.S. Shipbuilding" (1). The object of the project was to classify and analyze as many viable types of industrial measurement systems as possible for use in a shipyard. The following measurement systems were analyzed:

1. Photogrammetry including convergent, stereo, digital image processing, and automated analysis methods;
2. Digitizers, with sonic and infrared systems;
3. Theodolites, including standard manual optical instruments, computer linked systems, and motorized laser targeted systems;
4. Coordinate measuring machines; and
5. Lasers scanners.

The first five groups of systems were the focus of the first part of this paper. The second part of the paper is an on-site analysis of the following specific industrial measurement systems from the general groupings above:

1. Theodolite, with a directly attached and dedicated computer for automated analysis of measurements;
2. Photogrammetry, convergent, with an automated photogrammetric analysis system; and
3. Optical Laser, where bearing and range are obtained from a single point.

SYSTEMS ANALYSES

Table I shows and compares the cost, accuracy, manning requirements, set up time, time required to obtain results, and reliability for each system.

There are four distinctly different photogrammetric systems with possible shipyard applications. These photogrammetric measurement systems are all based on photographic processes, but the two methods by which the photos are taken, and the various methods by which they are analyzed, are significantly different.

	COST[1] ($1,000)	ACCURACY[2] (stated)	MANNING[3] (persons)	SET-UP (hours)	RESULTS[4] (days)
PHOTOGRAMMETRY					
CONVERGENT	100 - 300	1 : 50,000	2 - 6	4	0.5 - 3
STEREO	100 - 300	1 : 20,000	2 - 6	4	0.5 - 3
DIGITAL IMAGE	130 - 200	0.08 mm	2	4	0.2 - 1.5
AUTO ANALYSIS	225 - 275	1 : 200,000	1 - 2	4	0.2 - 1.5
THEODOLITES					
STANDARD MANUAL	5 - 50	0.025 mm	2 - 3	4	1 - 2
COMPUTERLINKED	40 - 100	0.025 mm	2	4	0.5
MOTORIZED, LASER GUIDED	350	0.025 mm	3	8	INSTANT
DIGITIZERS					
SONIC	10-25	0.10 mm	1	0.5	INSTANT
INFRARED	60	0.5 mm	1 - 2	0.1	0.5
LASERS					
THEODOLITES - LASER RANGE	190	1mm	1	4	INSTANT
SCANNERS	150	@1mm	1	4	INSTANT
COORDINATE MEASURE MACHINE	5-300	.025 - .0025mm	1	4	INSTANT - 1

1 A rough approximation of initial system cost. Costs vary significantly because of configurations available in the various instruments. A range of costs indicates a range for the cost of a typical, basic system to one with standard additional features.

2 Accuracy is stated in two different ways. An accuracy written as 1:50,000 is typical for a non contact type of measurement device such as photogrammetry, where the camera can be set at various distances from the object. For example, if the field of view is 20 feet across, a 1:50,000 accuracy will be 20/50,000, .0004 feet or .005 inches. The other method of accuracy description is a dimension directly on the object, such as .01 inch. An accuracy of 1/32 inch was considered acceptable for a shipbuilding measurement device.

3 Manning requirements am included as a range. Most all the systems could conceivably be operated by a single skilled person. The most efficient number of operators and assistants could range from 2 to 6, depending on the system and the turn-around time desired.

4 Time required to obtain results is a range dependent on the difficulty of the job and the number of points to be measured.

TABLEI

SUMMARY COMPARISON OF SYSTEMS

Convergent Photogrammetry

The convergent method is one of two methods of photogrammetric measurement. Camera stations are arranged such that camera axes are inclined, or meet at an angle, relative to a. normal view of the object and converge toward one another. Discrete points on the object must be easily identified in the photos or physically targeted, usually the latter. The positions of the various points of interest are determined by a complex mathematical 3-D triangulation network.

Typical photogrammetric measurement equipment consists of a terrestrial camera, flash units, photo development lab, analytic compiler, and a computer with customized software.

Known camera positions are required to perform the photogrammetric measurements. Some operators pre-survey camera locations relative to the measured object with theodolites. Some systems have simulation software to predict the best camera locations. Sophisticated programming of the triangulation schemes with a few pre-measured control points on the object allow determination of camera locations solely from analysis of the photos in the compiler.

Discrete points of interest must be manually targeted, usually with an adhesive backed bull's-eye. Camera placement should be carefully planned, possibly with the use of models, to eliminate delays at the sight or rework for lack of coverage. The effect of surroundings on locations and lines of sight should also be evaluated. The only required externally measured data are a few distances between pairs of points on or near the object which serve to establish scale.

Analysis of photographs is done on a photogrammetric analytic compiler, a machine for manually viewing and digitizing the photographs into numeric information for synthesis by computer. Each point of interest must be identified and targeted individually by the operator for entry into the computer file. The machine accurately records the two dimensional position of all visible points of interest in one photo at a time. The two dimensional positions from the various photos are combined in a complex triangulation network to fix the points in three dimensional space.

A key element in the analysis is rigorous analytical formulation of the mathematics involved and subsequent programming of the same to develop the analytical software. Processing by a computer can produce a variety of accurately scaled products such as tables of offsets, one-line diagrams and drawings.

Targeting of control points and otherwise difficult to identify points, such as flat surfaces, is required. Adequate lighting must be provided. Results are usually available one to three days after photography occurs, depending on the complexity the of structure, proficiency of the analytical machine operator, sophistication of the software analysis package and the capability of the computer.

Stereo Photogrammetry

The other standard method of photogrammetric measurement is the stereo method. Usually, two cameras are used at the same time to take two overlapping photographs called a stereo pair. Camera stations are arranged with roughly (± 10 degrees) parallel axes to the target and arranged to completely cover the subject with overlapping photographs. Relatively simple but complete manual digitizing of photographs is performed by a special photogrammetric analytic stereocompiler, then processed by a computer to produce a variety of accurately scaled products such as tables of offsets, one-line diagrams, and drawings.

The key difference between the convergent and stereo methods of photogrammetry is that the stereo photos are taken at nearly right angles to the object whereas the convergent photos are at various angles. Subjects of stereo photogrammetry need not be targeted, but discrete points of interest may be targeted. This feature is desirable when large areas must be surveyed and targeting would consume a large part of on site time.

The angle at which photos can physically be taken, dependent on access to the subject or other obstructions, is another factor to consider in selecting stereo or convergent methods. The inability to photograph an object at nearly right angles may prohibit the use of the stereo method. Accuracy of stereo photogrammetry is less than half that of the convergent method.

Camera stations should be located 15 - 30 feet from the object being measured. This distance can be reduced by the use of special cameras, or increased at the expense of less accuracy. Targeting of control points is required. Lighting may be required for poor light situations. Photographic analysis is done off site in an office environment. The imposition upon regular shipyard operations is no more than for convergent photogrammetry.

Digital Image Photogrammetry

Digital imagery is a refinement in the method of photogrammetric analysis. Photographic methods and triangulation techniques are basically the same as other forms of photogrammetry. Discrete points are located by the photo analyzer operator, then the computer creates a digital file for that point on that photo. The same points on related (roughly 60% overlapping) photos are similarly located, but measured automatically using digital correlation techniques and stored as digital image patches. Patches are distinct groupings of individual pixels (various shades of dots in the digitally stored picture) which define a particular point and its surroundings. These patches have smaller digital image files to keep computer storage space requirements low, but still include enough of the image for subsequent correlation.

The core of the system is the Digital Comparator Correlator System (DCCS) (2) which performs automatic point correlation analysis on about 80% of the points. This reduces operator involvement and fatigue significantly. In addition, the DCCS uses a post-process operation, called least squares correlation, which redigests all the correlation information to refine the final measurement.

However, the existing system, which uses convergent photos, has not been tried on a purely industrial application. A new system under development uses similar digital imaging but is designed to use stereo photos on a special analysis system and stereo pair viewing screen.

Site preparation, and imposition on regular shipyard work would be similar to that for the other photogrammetric methods. The operator identifies control points and other points of interest on the master photo; i.e., the first photo on which that point appears.

Points on the master photo are identified by the operator on subsequent photos, then automatically correlated to the master photos (by the digital image processing software) to perform the triangulation required for precise measurement. Once the integrated software performs the triangulation work, each point measured is identified as a set of x,y,z object coordinates.

Automated Analysis Photogrammetry

The only system in this category is the STARS (Simultaneous Triangulation and Resection System) (3). The method of photography is very similar to standard convergent photogrammetry. Therefore,. this description will dwell mainly on the specifics of STARS.

The key to STARS is the Autoset-l automatic monocomparator. The photographs are shot with use of retroreflective targets which must be manually placed on the object. A powerful strobe flash on the camera illuminates the targets which then show up as easily identified bright spots on the photographs. Once each overlapping photograph in the set that cover the object have been manually calibrated into the system, the Autoset-l automatically sights and analyzes each of these bright targets.

The system turns the collection of points from the photographs into digitized information. The software package then performs the triangulation analysis to measure the object. This information can be put into a form readily usable by another system, or produce offset tables in the measured object's coordinate system.

The main advantage of STARS is that the operator of the monocomparator is spared the arduous task of manually and visually identifying each point to the system. The operator simply identifies a few control points to marry one overlapping convergent photograph to the next then lets STARS collect all the other points.

Sonic Digitizer

Sonic Digitizing is a method of 3-D position indicating that works on the principal of analyzing the time for a sound generated at the point of measurement to travel to a grid of calibrated microphones (4). A spark emitting probe is manually positioned (or attached in the case of motion analysis) at the point on the object to be digitized. A spark is generated at the end of the probe. A precisely placed system of four microphones, mounted on a rack lying in a single plane, each senses the distance to the probe by timing the signal. The timed signal is processed to a digitized electrical signal and recorded in a file, on the host computer. Post-processing of the raw signal establishes a data file of coordinates based on the measured object's coordinate system.

The volume of optimum measurement is limited with this device to a 12 foot cube. Measurement within a 25 foot cube is possible with some loss of accuracy. The item to be digitized must be accessible to the operator to point the entire surface with the emitter probe. Up to 16 probes can be accommodated by one device, but for an industrial measurement project not involving dynamics, too many probes would be overkill.

A number of operators can work one system simultaneously using probes emitting different frequencies to measure different parts of an object at the same time. Conversely, one operator can use one probe set at different frequencies to identify different parts of the same object. For example, one frequency can be used for plating, one for stiffeners, and another for pipe. The different frequencies show up on the graphics display as different colors or coded by different symbols.

Each point on the measured item must be in a clear line of sight of at least three of the microphones. Areas much larger than the limit for required accuracy can be done piecewise by moving the object or microphone array to provide overlapping coverage. Welding in the immediate vicinity is likely to interfere with the system. Extreme air movement in the area must be limited.

A multiplexer unit converts the sound data to ASCII format for processing by computer. The basic software included with the system catalogues output and performs simple spatial calculations to give an x,y,z data file. The data can be presented in various two dimensional views of the three dimensional objects.

Infrared Digitizer

The infrared digitizer is similar in principal to the sonic digitizer in that a signal generated at the point to be measured is received by a device, set in a predetermined reference frame, to determine the position of the object. The only system known to fall in this group is called OPTOTRAK (5).

The OPTOTRAK measurement system consists of up to 256 light emitting diodes as markers either attached to or made to contact the object at points to be measured. As the marker is activated it is sensed by at least 2 but up to 24 dual axis infrared position sensors, or cameras, which determine a line of sight to the marker. Sets of two dimensional coordinates are analyzed to give a three dimensional position for each of the markers. The system was developed primarily

for motion analysis but is adaptable to industrial measurement. It is presently limited to a 5m (16 ft) radius from the camera to the marker, but is adaptable to larger scale projects without motion.

The system requires 120V power and must be isolated from other infrared light sources. Maximum cabling distances have the controller unit 30m (100 ft) from the cameras and the host computer 45m (150 ft) from the controller. The object must either be pre-targeted with wired emitters or accessible to a technician to direct a probe to the object for contact measurement.

Standard Manual Theodolites

Theodolite industrial measurement systems are logical adaptations of standard land surveying instruments. These optical instruments measure horizontal and vertical angles and are usually operated in pairs for industrial measurement. When a line of sight from two instruments intersects on a point on the object being measured, the point is fixed in space. The horizontal and vertical angles associated with each point are then converted to 3 dimensional coordinates through 3 dimensional triangulation algorithms.

The best modem systems for industrial measurement employ electronic theodolites tied into a computer with software to quickly compute the positions the instant both "guns" are set on the target.

The operator(s) must have reasonable line of sight access to the target along most of the surface being measured. Theodolites can be moved and reset to cover different parts of a difficult to cover target, but such a procedure increases measurement time and complications. Items are usually targeted so that both theodolites are positively aimed at the same point. Movement of heavy machinery near some measurement sites can upset theodolite calibration and should be minimized.

The basic, manual adaptation of the land surveying theodolite measuring is a manual theodolite. Manual instruments sight on cross-hairs through a magnifying telescope to measure horizontal and vertical angles. They are usually mounted on a tripod and a tribrach for leveling. Simple instruments have external micrometer type scales and, even if of high quality, are limited in their accuracy. Better instruments have lighted, enclosed and magnified optical micrometer scales which can be more accurate, the best of which virtually eliminate human error in reading the scales. The best and most accurate machines have electronic digital readouts which make reading much easier and less error prone.

The difficulty of processing data can range from tedious and time consuming to very simple, depending on how advanced the system is. A very simple system will require hand recording of measured angles and manually calculated basic trigonometry to determine 3-D positions. Data should be reduced by computer using readily available software that includes error analysis of the theodolites being used. Good software can usually arrange the output in a form directly useable by a shipyard's main computer. The biggest problem with a manual system is visually reading the theodolite scale and either writing the readings for later analysis or verbally calling the readings to a third person who records them in writing, and then enters them into the computer or manual calculation routine, a tedious and error prone system.

The measurement site should be isolated from heavy machinery movements. The object is usually targeted for easier point recognition. Lighting may be needed if the measurements are taken at night to avoid other work, normal passage of heavy machinery, or intense sunlight. For efficient measurement, reasonable access to the object must be provided.

Computer Linked Theodolites

An advanced theodolite system is one that is directly linked to a computer for instant and automatic analysis. Although such systems are still manually sighted, they use electronic theodolites that send the measured angles to a dedicated host computer for instant analysis. Systems that fall into this group are the

1. AIMS II (Analytical Industrial Measuring System) (6;
2. CAT 2000 (Coordinate Analyzing Theodolite) (7); and the
3. ECDS 2 (Electronic Coordinate Determination System) (7).

The key differences between the basic and the advanced theodolite systems is the direct link to a computer. Thus the possible human errors in optical scale reading and in data recording of a manual system are avoided. This also means that the data are fed directly to a system designed specifically for the industrial measuring task so that results are instantaneous once the system is established in the object's coordinate system.

The systems are available with laser beam generators for targeting. This arrangement insures that both instruments are focused on the same object and eliminates the need to manually target the object with proper light conditions.

Computer software designed specifically for these systems speeds the process of setting up the instruments, corrects measurements for instrument misalignment, has special routines to protect against power loss and incorrect readings, and many other advantages of a purpose built system.

The only difference for planning purposes is that a power source must be provided to the computer. The theodolites alone can be run on batteries but the standard host computer needs power. An adaptation of the system, although limited in on-site data information capacity, uses a portable computer.

Motorized. Laser Targeted Theodolite

An advanced theodolite system is AUTOCAT (6), short for AUTOmated Coordinate Analyzing Theodolite. The AUTOCAT measurement system consists of at least two digital cameras mounted in electronic, motorized theodolites and directly linked to the host computer. A third electronic, motorized theodolite is a laser beam generator used for targeting and providing a third reference line. The system can be computer driven based on the table of offsets from the object, or operated by a joystick based on the live images from the digital cameras.

In either mode, the laser is directed at the point to be measured. The two digital cameras are also directed to the general position of the laser spot and a digital image of the laser spot is analyzed for its position relative to the true axis of the reading theodolites. The analysis fixes the position of ‘the point in space.

The laser theodolite can be used as a third reference line but tends to make the system less accurate. The laser spot is actually a revolving circle of light if seen at a right angle to a surface. At any other angle it appears as a revolving ellipse. The analysis of the image from the digital cameras can compute the centroid of the ellipse and give a better line of position than the pointing of the laser alone.

An additional planning requirement is that the analysis of the laser dot requires somewhat controlled light conditions. The demonstration of this system was inhibited by bright sunlight making, the laser dot barely visible to the digital cameras and at some angles blinding the cameras. These drawbacks negated the field test of AUTOCAT.

Operational advantages are similar to that for the STARS photogrammetry system in that operator fatigue is greatly reduced so that measurements can be made more reliably and quickly. However, the on-site hardware of the system is heavy and bulky, with a fair number of cables, making it less than portable.

Laser Ranged Optical Theodolite

A relatively new system called ACMBTER (Accuracy Control METER) fills this category. ACMETER (8) works on the principal of obtaining a bearing and range from a known location to fix a position in space. This is similar to getting a bearing and range from a radar for navigation.

ACMETER obtains the horizontal and vertical bearings with a single, optical theodolite. Built into this same instrument is a range finding laser. The two work together to give a fairly accurate bearing and range to a point on the object.

The integrated system contains the ACMETER, a directly attached computer-like black box, laser reflective targets, and software to digest all the triangulation. All points of interest must be targeted, not only to make positive identification, but to provide the laser with a good reflective surface to get accurate distance readings.

Coordinate Measuring Machines

Coordinate Measuring Machines (CMM) are mechanical contact devices with mechanically actuated x,y, and z axes for accurately measuring 3-D items. They are usually used for precise measurements of machined surfaces of relatively small parts. The largest machine surveyed could measure a part 2m x 11m x 3m (6ft x 33ft x 10ft) (x,y,z). The best machines are relatively slow but extremely accurate and sensitive. As such, they are not ideally suited to the shipyard environment of dust, vibration and less stringent accuracy requirements. Some manufacturers will “downgrade customize” their machines to the desired accuracy and the environmental conditions encountered, but other types of measurement systems are more appropriate.

Laser Scanner

The only known laser scanner type system is the tracking system designated the LTS-310 (6). The LTS-310 was developed as a very accurate device for measuring moving objects. A special laser reflector is attached to the object at the point to be measured, then the system casts a scattered laser beam in the general direction of the reflector and detects the reflection to determine its position in space. The system was not developed for stationary industrial measurement, but should be adaptable.

System planning requirements seem to be as simple as targeting the object and fixing the position of the LTS-310 relative to the object before starting. The system is still under development.

FIELD TESTS

This section is an account of field tests of the three specific industrial measurement systems that were made available by the manufacturers. The testing was performed under somewhat realistic conditions at NASSCO. The following systems were evaluated:

1. <u>Theodolite,</u> with a directly attached and dedicated computer for automated analysis of measurements;

2. <u>Photogrammetry,</u> convergent, with an automated photogrammetric analysis system; and

3. <u>Optical Laser</u>, where bearing and range are obtained from a single point.

A laser targeted automated theodolite system was also tested, but the bright sunlight made the laser unreadable by the cameras. The system needs further development before use in most shipyards.

General planning for all of the field tests consisted of:

1. Determining which block was to be measured;
2. Identifying discrete points of interest to be measured;
3. Determining the type of coordinate system to be used (local or object);
4. Identifying control points and construction of a control file;
5. Placing the instrument(s) at the job site;
6. Orienting the coordinate system axes;
7. Checking for sight line interferences and space limitations; and
8. Determining any system specific operating restrictions.

All the systems tested required placement of targets on the object. Differences in the types of targets are significant. Discrete points of interest to be measured were chosen because they represent two areas of concern to the shipbuilder. One concern is that of accuracy control and quality improvement for building an assembly to specification. The other is that of unit fit-up during the erection process to minimize rework.

The accuracy requirements (tolerances) for the various parts embodied in the aft erection butt of an assembled block were:

1. Shell plate panel: Length +/- l/8 in. and Chord +/- 1/8 in;
2. Longitudinal and shell stringer placement on the deck, longitudinal bulkhead and side shell: +/- 118 in;
3. Transverse bulkhead on bulkhead/deck sub assembly: +/- 3/16 in; and
4. Final assembly: +/- 1/4 in.

<u>Computer Linked Digital Theodolite</u>

The specific system tested was Kern Instruments Inc.'s "Electronic Coordinate Determination System" (ECDS-2). Kern has been bought by another company and the ECDS-2 is no longer marketed in this country, but similar systems are available. The object of the test was to check the positions of longitudinals, shell stringers, decks and bulkheads of the aft erection butt of a completely assembled bilge block. Figure 1 shows an isometric of the erection butt and the targeted points.

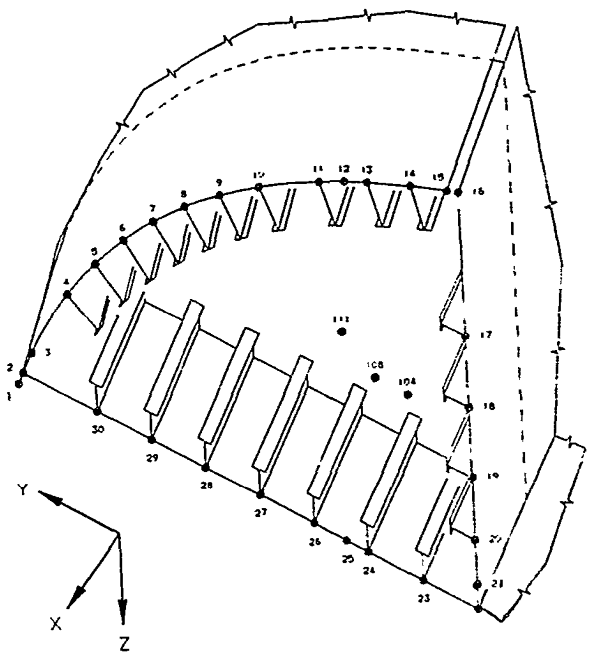

FIGURE 1

ERECTION BUTT AND TARGETS

In planning a theodolite set-up, it is necessary to determine whether a local or object coordinate system will be used. A local system produces offset data with the origin of the coordinate system at one of the theodolites. An object system produces offset data relative to the ships coordinate system. However, to use the object system, three known points (control points) are required by the computer software to set up a coordinate system. In this test the object system was used.

The control points can be obtained in a number of ways. If three points on the object are known precisely i.e., from the ship's offset file, the impact of the mathematical best-fit algorithm and, therefore, the residual error applied to the individual measurements, is minimized. Since there is already some question as to the built dimensions of the object, the ideal method is to locate the control points off the object of interest. However, this is difficult to achieve because each theodolite must "see" the control points. Measurement geometry restrictions associated with placement of theodolites does not facilitate the use of off object control points.

A second method to obtain the control points is to measure three or four points in a local system and, using the transformation software module, translate and rotate each point from a local system into an object system.

For this field test, two control points on the erection butt and one on the transverse bulkhead (required for depth), taken from the ship's offset file, were used. When using either a local or object coordinate system, it is necessary to input the x, y, and z coordinates of the control points into a control file. The software accesses this file when setting up the coordinate system.

The coordinate system must be oriented properly to avoid anomalous output. In this case, the block was upside down with the z-axis rotated downward.

Theodolite placement at the site requires clear sight lines to each target. An angle of 60 to 120 (maximum) degrees between the lines of sight from the theodolites to each target should be maintained to achieve acceptable accuracy. Outside these limits, accuracy decreases markedly. Figure 2 shows a typical measurement geometry. For this field test, adequate space was available to maintain an acceptable angle between the lines of sight and yet still be able to measure the complete erection butt without repositioning the theodolites. However, there are many areas within a shipyard where space is limited, i.e., in assembly, outfitting, storage, etc., which makes measuring the object more difficult and, therefore, increases costs.

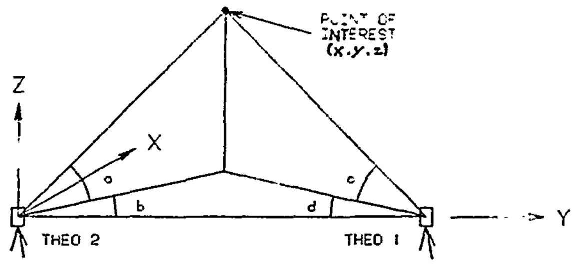

FIGURE 2

THEODOLITE MEASUREMENT GEOMETRY

A number of operating restrictions that affect accuracy must be considered when planning a measurement job. These are:

1. Thermal expansion of the object if exposed to direct sunlight;
2. Ground compression from gantry cranes, mobile cranes, heavy forklifts and trucks in the immediate vicinity of the theodolites;
3. Stability of surfaces on which the theodolites are set; and
4. Thermal expansion of the theodolite in direct sunlight.

Individual discrete points of interest on the object must be highlighted with some type of target. For this evaluation, 1" by 1" adhesive backed, aluminum foil cross haired targets were used. For this field test, which required targets on the edge of shell plates, etc., standard targets proved cumbersome. A better solution was to use a small punch mark (approximately l/16 in. diameter) filled with a drop of yellow paint. In all, the erection butt required 33 targets and placement was such that each was visible from both theodolite positions. Points of interest that were targeted (Figure 1) included the positions of deck and bulkhead longitudinals, shell stringers, sight edges, and a transverse bulkhead. A lift was required to place many of the targets.

The on-site operating procedure included placement of the targets, equipment set-up, removal of sight-line interferences, and the measurement. Equipment assembly and disassembly consisted of setting up and positioning two tripods, attaching theodolites to the tripods, leveling tripods and theodolites and connecting cables between the theodolites, power box and the computer.

Orientation of the coordinate system was done by pointing the theodolites in the directions of the X and Y axes and at each other. The distance to one control point from both theodolites was measured with a tape measure. Then the three control points and the scale bar were sighted-in and the bundle adjustment made.

The "bundle adjustment" is the mathematical triangulation process the computer uses to set up the coordinate system. Computer process time may be 1 to 2 minutes and may not be successful if there has been an operator error in sighting in the control points, recording the control points, or the control point coordinates are incorrect as entered into the control file. The accuracy of the coordinate system is reported in terms of Root Mean Square (RMS) (in, ft, or m) and indicates the amount of error that is to be applied to each individual measurement to be taken in the "On-Line" mode.

After the coordinate system has been created in the bundle adjustment, it is a relatively simple but tedious matter to manually sight-in the points of interest in the "On-Line" operating mode. Each operator sighted-in on the target, the RMS error was checked for acceptability, and the point was recorded. The coordinates of each point of interest are displayed instantly on the screen and stored to a file. The time necessary for sight-in is approximately 1 minute per point.

The output offset data analysis is performed to build confidence in the system's ability to deliver accurate data (in the form of offsets) for the process tested and to check the usefulness of the output. The accuracy achieved by the ECDS-2 system is reported in two parts.

Part one is the accuracy (error) of the bundle adjustment which is reported terms of a Total Root Mean Square (RMS). For this bundle adjustment the RMS error was 0.0002 ft. The Total RMS error is applied to each point of interest recorded in the "On-Line" mode as a correction factor. The second part of the accuracy reporting is the RMS error associated with each individual point of interest measurement in the "On-Line" mode and indicates the amount of error for each measurement.

The process accuracy- was tested by comparing machine produced point to point measurements (using the "Distances Function" of the "Special Functions" module) and comparing them to three manually measured (via tape measure) point to point measurements. In both cases, the system reported accuracy and the' accuracy from the point to point accuracy comparison were found to be well within the required process accuracy.

The usefulness of software produced output was tested by a comparison of the design offset file to the machine produced offset file. The software makes provisions to compare one measurement offset job file to another. However, no provision has been made to compare a Kern produced offset file to a ships offset file. This leads to a tedious and time consuming manual comparison to determine the difference between the nominal (design) values and the theodolite measured values. End usefulness is enhanced by the conversion module which converts decimal feet to feet, inches, and fractions.

This particular field test is representative of any large 3-D measurement job, i.e., blocks, large subassemblies, etc.; consequently, time required to target and measure smaller subassemblies and fabricated parts will be considerably less.

Man-hours and time required to complete one measurement job is a function of the number of targets to be placed, the difficultly placing them, and the number of points to be measured. Generally, the man-hours and time required for planning, assembly and disassembly, orientation, bundle adjustment, and data analysis are fixed.

The Digital, computer linked theodolite is a relatively low cost, accurate instrument applicable to almost any shipbuilding process. However, it is not without its shortcomings. Advantages and disadvantages are listed in Table II. A relatively simple measurement job takes nearly 7.25 man-hours. With careful scheduling, coordination and a well trained and experienced two person crew, efficiency may be increased to complete two measurement jobs of this type per 8 hour shift. The many shortcomings of this system do not recommend it for applications where large numbers of measurement jobs in many different locations are required.

The AIMS 2 (Analytical Industrial Measuring System) (5) and the CAT 2000 (Coordinate Analyzing Theodolite) (6) system are systems very similar to the ECDS2.

<u>Convergent Photogrammetry. Automated Analysis</u>

Photogrammetry is the science of acquiring and interpreting 3-dimensional data of physical objects by recording, measuring and analyzing photographs. The system field tested was Geodetic Services, Inc.'s "Simultaneous Triangulation and Resection System" (STARS) (3).

Data acquisition is performed by the photogrammetric camera, utilizing retroreflective targets highlighted by a strobe light to assure instantaneous target definition and produce photos with 2-dimensional x-y coordinates. With more than two exposures of the object from different locations, multiple horizontal and vertical angles describe each point of interest (Figure 3). 'Accuracy errors are minimized through redundancy. The actual 3-dimensional positions of the points of interest are calculated off-site.

ADVANTAGES

1. Relatively low capital cost.
2. Accuracy adequate for shipbuilding tolerances.
3. Applicability to many processes.
4. Real time results.
5. Rugged and reliable.
6 Software menu driven.

DISADVANTAGES

1. Due to time required to target, set-up and take-down equipment and operate, the system is inefficient and costly to operate for timely completion of large numbers of measurement jobs.
2. Experience with the system is necessary to use the system effectively.
3. Extreme angles between theodolites and between the theodolites and the targets must be avoided.
4. A stable platform is required for the theodolites.
5. Theodolites are unable to "see" targets if object of interest is back)lighted by the sun or if the sun's rays shine directly into the lens.
6. If the job has a large quantity of points to be measured, the operators may become susceptible to theodolite sight)in and computer input error through fatigue.
7. Targeting is required.
8. Illumination of object necessary for low light measurement jobs.
9. Measurement on large objects in tight spaces is difficult, i.e., two blocks positioned close together in an assembly, storage area, etc.
10. A minimum crew of two persons required for efficient operation.
11. Motorized transportation for the system is desirable due to its bulkiness.

TABLE II

ECDS2 SUMMARY EVALUATION

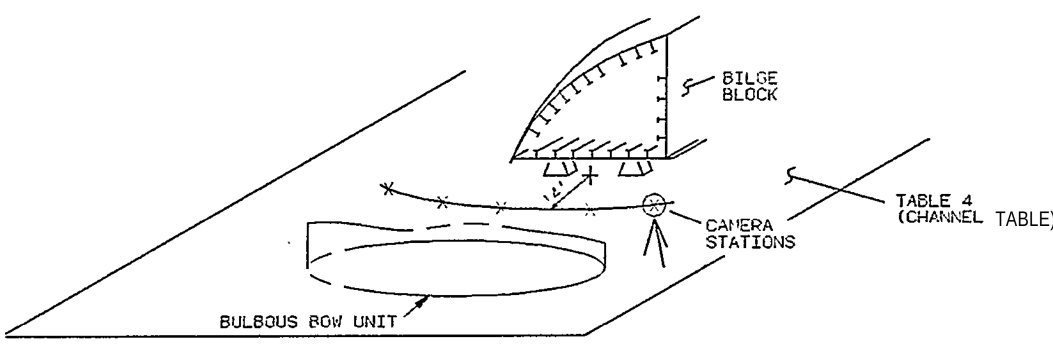

FIGURE 3

STARS CAMERA STATIONS

The photogrammetric camera is of "medium" format (4 l/2 in. by 4 l/2 in.) and, as opposed to glass plate types of cameras, it is a microprocessor controlled and monitored roll film camera. This camera minimizes the inherent errors introduced when using roll film through vacuum stabilization and internal calibration marks.

Two dimensional coordinates are extracted from the negatives by the AutoSet monocomparitor which is automated and computer driven ,requiring very little human intervention or skill to operate. The bundle adjustment used is a best-fit algorithm based on the familiar mathematical model originally developed for photogrammetry and runs on a personal computer.

Accuracies of 1:250,000 of the size of the object are achievable, depending on the number of photographs taken and the positions of the camera stations.

Photogrammetric network modeling and optimization is accomplished through a Computer Aided Design (CAD) based, interactive "Photogrammetric Simulation Program" (SIM) supplied with the STARS Standard Software Package. The photogrammetric simulation program minimizes on-site time and optimizes accuracy for the available space by predicting the number and position of camera stations, camera aim points and the number of photos per station required for complete coverage.

The on-site operating procedure included target placement, set-up and take-down of equipment and measurement job execution.

Special targets must be placed at all points of interest. The targets are adhesive backed, 5/16 inch diameter, and retroreflective. Equipment assembly and disassembly was a simple matter of attaching and detaching the camera to the tripod (the camera can also be hand held), positioning the scale bar and moving the camera to each of the five predetermined stations.

The execution of the measurement job, which took place in the rain and without interruption of on-going production work, required 20 minutes. Fourteen photographs were taken from five different positions on an approximately 14 ft. arc radius from the object (Figure 3).

Data Analysis

After the development of the photos, extraction of the point of interest x-y coordinates from seven of the fourteen photographs was accomplished with the AutoSet monocomparitor and accompanying software. The operating procedure consisted of:

1. Mounting the first negative on the digitizer pad and a duplicate negative on the AutoSet;
2. Entering some start up information;
3. Manually digitizing one fiducial (internal control reference point) and one reseau (internal film calibration points). The AutoSet automatically drives to and measures the remaining three fiducials and 24 reseaus; and
4. Manually digitizing three to six targets.

The AutoSet automatically drives to and measures the remaining targets by utilizing the original object offset file to calculate the approximate positions of the points of interest. As the AutoSet works, it may not be able to measure an occasional point. These targets are stored in a review file for the operator to attempt to manually digitize when the mensuration of that particular negative is completed.

After the first negative is finished, the process is repeated for the remaining six negatives. The final step is to execute the bundle adjustment which takes approximately l-2 minutes on a personal computer.

The procedure required 1 hour and 10 minutes to analyze seven negatives. If no prior information is known about the points of interest (i.e. no offsets available), the procedure requires approximately l/2 hour more time to establish approximations to allow the AutoSet to automatically drive to and measure the targets.

Upon completion of the bundle adjustment, accuracy indices are produced by AutoSet as standard deviations in each of the the x, y and z directions which, unlike the theodolite bundle adjustment, processes and calculates the x y, and z coordinates of each point of interest in one batch. The standard deviations for this field test were x = 0.13mm (0.005 in), y = 0.08mm (0.003 in), and Z = 0.08mm (0.003 in). These deviations are applied to each individual measurement as an error correction factor. The ability of the system to meet the process accuracy was tested by comparing the STARS produced point to point measurements with those produced manually by tape measure. As indicated by the bundle adjustment standard deviations and the point to point comparison, the system is capable of accuracies well above those required in the shipbuilding environment. The accuracy produced is proportional to the square of the number of photographs taken of a point of interest at each station. To achieve shipbuilding accuracies a minimum of two photographs are needed.

The convergent photogrammetry system evaluated, STARS, is an accurate and flexible measurement system, well suited to the varied applications and environmental conditions found in shipyards. Advantages and disadvantages are shown in Table III. Integration into the total production process is enhanced by the system's off-site planning capabilities and minimized on-site time for the efficient inspection of a large number of objects. Conversely, use of the STARS system as an on-site building tool is handicapped by the short but distinct delay for results feedback.

Similar systems are available from Wild Heerbrug and John F. Kenefick Photogrammetric Consultant, Inc.(Wild/JFK Industrial Photogrammetry System) and from Rollei Fototechnic GmbH & Co KG, Instrument Division (Rollei Fototechnic Photogrammetry System).

ADVANTAGES

1. It is applicable to many production processes.
2. It is flexible and able to overcome adverse environmental or varied measurement geometry conditions;
3. The camera is rugged, reliable, and designed for ease of maintenance;
4. The monocomparitor is highly automated and the number of points of interest that can be measured is essentially unlimited;
5. Accurate to shipbuilding processes .
6. Requires only one person for planning, on-site execution, and off-site data reduction.
7. High skill level not necessary
8. Efficient for large quantities of measurement jobs where real-time results are not necessary,
9. Data acquisition is highly redundant for consistent results.
10. No illumination of object required.
11. No control points required to set up the coordinate system.

DISADVANTAGES

1. High capital cost
2. Targeting required.
3. Results turn around is not real time and is dependent on the number of points of interest.

TABLE III

STARS SUMMARY EVALUATION

Optical Laser

The optical laser based coordinate measuring device is a hybrid, a combination theodolite and laser that uses the common navigational principle of bearing and range in a predetermined 3-dimensional coordinate system to locate a point in space. The angles (bearings), between the line of sight from the measuring device to the target and the x and y axes of the coordinate system, are determined by the optics (much like a theodolite). Distances (range) to the targets are measured by a laser. The system uses dedicated hardware to perform calculations (as opposed to software) on the horizontal and vertical angles and the distance to calculate the x, y and z coordinates of the point of interest (Figure 4). The system is similar in some respects to the operation of digital theodolites, but is freed from many of the measurement geometry restrictions inherent in theodolite systems by using only one measuring device.

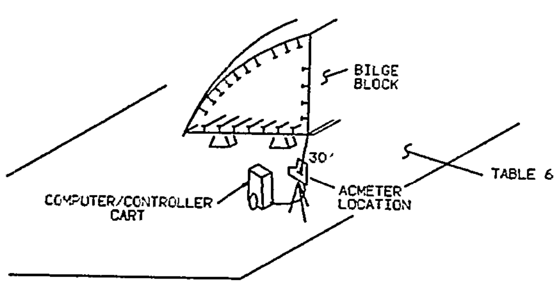

FIGURE 4.

ACMAN MEASUREMENT GEOMETRY

The system field tested was Prometrics Oy's "Manufacturing Accuracy Measurement and Control System" (ACMAN) (8). The total system has been developed, specifically to measure and support the construction and process improvement of hull block sub-assembly, assembly and erection. The system consists of 3 parts: the coordinate measuring device (ACMETER), a relational database for data storage and statistical process control (ACBASE), and a graphics package (ACCAD) for modeling shapes. The ACBASE and ACCAD software systems are designed to be interfaced (in terms of downloading files) with a yard's database and CAD systems to provide real time, on-site comparisons of the measured points of interest from their design values. Also provided are graphics routines to represent the object and automatic statistical process control chart graphing for process improvement. The software can also be customized and tailored to a yard's individual needs by the manufacturer.

The ACMAN system is capable of measuring points of interest in either local or object (block) coordinate system. The block coordinate system was used in this field test. Control points are used to establish the orientation of the block and object coordinate systems. The ACMAN system does not use an iterative mathematical best fit solution (i.e., the bundle adjustment) to ensure the accuracy of the points of interest measured. Three precisely known points are required for system orientation. It is necessary to know the precise coordinates of the control points because the accuracy of the measured points of interest is directly proportional to the accuracy of the control points. This is different from theodolites, which are able to calculate an acceptable coordinate system (with some error) even though the three control points may not be in the exact positions entered into the control file.

Three control points must lie on a plane and are used to establish the x, y plane. Two of these three control points are used to define the direction of the x-axis. The z-axis is automatically set 90 degrees to the x-axis for a right handed coordinate system.

Theoretically, and in practical application, it is best that these three control points not lie on the object being measured since there is already some question as to the dimensions of the assembly. This is especially so with the ACMETER due to its one to one accuracy relationship between the control points and the points of interest to be measured. Determining these three off-object control points was not practical for this field test; however, with an in-yard capability, this is a desirable and practical method to use and is facilitated by the one measurement station requirement.

The ACMETER (with its tripod) must be placed such that all control points and points of interest are visible. With only one measurement device necessary, the placement of the ACMETER is very flexible and adaptable to the available space. In this field test, the ACMETER was placed off to one side of the block to demonstrate its placement flexibility. The z-axis of the block is downward and perpendicular to the ground.

The ACMETER is most effective at a distance from the object of between 3m (9.8 ft) and 30m (98 ft).

Individual discrete points of interest on the object must be highlighted with the manufacturer supplied adhesive backed, bulls- eyed targets. To optimize accuracy for this test, which required targets on the edge of plates, the targets were placed at an angle to the object so that the operator's line of sight remained perpendicular to the targets which. The erection butt required 29 targets.

Equipment assembly and disassembly consisted of wheeling the cart containing the ACMETER, lap top computer and laser power unit into position, setting up and positioning the tripod, attaching the ACMETER to the tripod and connecting cables between the measuring device, laser power source and the computer.

Actual measurement was a two step process Orientation of the coordinate system was first. In the local system, the 3 control points, which define the reference plane, were sighted in and entered. The system does an automatic transformation of the control points from a local to a block coordinate system.

After the coordinate system has been created it is a relatively simple but tedious matter to sight-in the points of interest. The coordinates of each measured point are instantly displayed on the screen and stored to a file. Time for point of interest sight-in is approximately 1 minute per point.

The ACMAN's systems capabilities for data manipulation and statistical process control were presented but could not actually be demonstrated. During the measurement process, a measurement form was generated on-site which presents the x, y, and z coordinates of each point. When the offset file of the whole object is down-loaded, the nominal (design) values and the difference between the nominal and measured values are also presented. Statistical process control is displayed in the form of histograms, X-bar and range chart is also available on-site.

The ACMAN system is a well thought out system, accurate to shipbuilding tolerances and applicable to many of the processes described in this report. 'Advantages and disadvantages of the system are shown in Table IV. Of the 3 systems field tested, ACMAN system strikes the best overall balance between flexibility, timely feedback, and acquisition cost. The system produces on-site real time results, with on-site operation ease approaching that of photogrammetry, and an increased measurement geometry flexibility over theodolites. It also presents many possibilities for total production process integration.

The ACMAN system seems particularly well suited to on-site building and inspection tasks during all phases of hull block construction. No similar systems are available.

ADVANTAGES

1. Developed for the shipbuilding industry.
2. Accurate to shipbuilding tolerances.
3. Applicable to many processes.
4. Rugged and reliable.
5. Integrated accuracy control and graphics.
6. Real time results.
7. Flexible; fewer measurement geometry restrictions.
8. One person operation.
9. On-site real-time feedback.
10. High skill level not necessary.
11. Results are absolute assuming control points precisely known.

DISADVANTAGES

1. High capital cost.
2. Stable platform required.
3. The ACMETER is unable to "see" targets if the object of interest is back lighted by the sun or if the sun's rays shine into the lens.
4. If the job has a large quantity of points to be measured, the operators may become susceptible to error through fatigue.
5. Targeting required.
6. Illumination of object necessary for low light measurement jobs.
7. Control points must be used to orient the block and object coordinate systems.

TABLE IV

ACMAN SUMMARY EVALUATION

CONCLUSIONS

Figure 5 is a generalized comparison of the three systems field tested. It shows a very clear inverse relationship of initial cost to the cost per measurement.

	Measurement System		
	Theodolites	Photo-grammetry	Optical Laser
Man-hours per Measurement	7.25	4.17	2.86
Cost per Measurement*	$ 362.50	$ 222.50	$143.00
Cost per System**	$65,000 .	$210,000	$182,200

* Based on average consultant labor rate of $50.00/hr.

• * Depends on options selected.

FIGURE 5

COST PER MEASUREMENT

Table V relates measurement tasks for the construction processes to the most appropriate measurement technique of those systems field tested. Each stage of construction is broken down into its constituent processes; furthermore, each process contains a number of measurement tasks that support "neat" hull block construction. The assigning of the numerical rank was subjective based on the evaluation of both qualitative and quantitative factors, There is no one system that has the capability to efficiently perform every measurement task. Therefore, this guide is suggested as a starting point for a, shipyard's investigation of its own needs for measurement techniques.

The most apparent aspect of the chart is that none of the measurement systems surveyed has the capability to conveniently and accurately measure both fabrication parts and large blocks. It seems that a complete measurement capability at a particular shipyard would use two or three complete types of systems, possibly with multiples of some of the less costly systems for measuring parts on an assembly line. It is also important to remember that nearly all the systems are under continuous development so that disadvantages described may be overcome by advances in the technology.

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Legend

1–Good Efficiency
2–Fair Efficiency
3–Poor Efficiency
N/A–use mannual method

Stage of Construction		Processes		Measurement Techniques: Digital Theo-dolites	Measurement Techniques: Photo gramm etry	Measurement Techniques: Optical Laser
Stage of Construction	Fabrication	Cutting Tees	Length, Prep of Cut, Degree of Bevel, Degree of Cut	N/A	N/A	N/A
	Fabrication	Stripping Plates	Width	N/A	N/A	N/A
	Fabrication	N/C Cut Plates	Length, Width, Diagonal	3	1	2
	Fabrication	Stripping I to Tees	Width of Stripped Flange	N/A	N/A	N/A
	Fabrication	Bending Tees	Chord, LOA, Sightline	3	1	2
	Fabrication	Bending Tees (Compound)	Chord, LOA, Sightline	3	1	2
	Fabrication	Bending Plates	Chord, Radius	N/A	N/A	N/A
	Fabrication	Twisting Tees	Angle from Vertical	3	1	2
	Fabrication	Rolling Plates	Length, Width, Curvature, Sight Line	3	1	2
	Sub-Assembly	Paneling Plates	Length, Width, Diagonal	3	1	2
	Sub-Assembly	Paneling Web Frames	Length, Width, Diagonal,	3	1	2
	Sub-Assembly	Fitting Out Web Frames	Length, Width, Diagonal,	3	1	2
	Sub-Assembly	Fitting Longs to Plate Edge	Relationship of Longs to Plate Edge	3	2	1
	Sub-Assembly	Web Frames on Sub-Assembly	Declivity of Webs	3	2	1
	Sub-Assembly	Web Frames to Plate Edge	Relationship of Webs to Plate Edge, Declivity of Webs	3	2	1
	Sub-Assembly	Final Sub-Assembly Check	Length, Width, Diagonal	3	1	2
	Assembly	Sub-Assembly Joined to a Sub-Assembly	Length, Width, Diagonal	3	2	1
	Assembly	Setting Pins on Assembly Table	Heights	3	1	2
	Assembly	Positioning Panels on Pins or Jigs	Position of Corners	3	2	1
	Assembly	Panelling Curved Shell Grand Panel	Lengths, Chord, Diagonal	3	2	1
	Assembly	Final Block Assembly Check	Length, Width, Diagonal, Key Hard Pts, Reference Lines	3	1	2
	Erection	Pre-Erection:				
	Erection	Layout Ways/Graving Dock w/Buttock and Frame Reference Grid	Lengths, Widths	2	3	1
	Erection	Check Offset Dimensions of Key Hard Points on Transverse and Longitudinal Erection Butts of Block to be Erected and its Mating Block(s)	Deck & Bhd Longs, Girders, Sight Edges, Shell Stringers, Web Frames, Reference Lines	3	1	2
	Erection	Check Squareness of Frames to Reference Buttock Line of the Block to be Erected	Perpendicularity of Frames to the Buttock Reference Line	3	2	1
	Erection	Erection:				
	Erection	Set Block and Check Position of Reference Lines on the Block to Reference Lines on Ways	Offsets of the Block Reference Lines to Ways Reference Lines	2	3	1
	Erection	Check Positions of Key Hard Points on Tranverse and Longitudinal Erection Butts of Erected Block and Next Mating Block(s)	Deck & Bhd Longs, Girders, Sight Edges, Shell Stringers, Web Frames, Reference Lines	3	1	2
	Erection	Check Frame Spacing Between Blocks, Half Breadths and Heights to Maintain Overall Tolerances	Length Between Reference Frames, Half Breadths and Heights Above Baseline	2	3	1
	Erection	Check Height of Keel Blocks to Maintain Baseline	Height of Keel Blocks	3	2	1

TABLE V

CONSTRUCTION PROCESSES vs.MEASUREMENT TECHNIQUES

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Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24,1990

Index Based Management Information Systems: A Study in Structured Operations

3A-2

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ABSTRACT

In any job, project, program, or complex undertaking there exists a need to understand all aspects of the work. This understanding is necessary to satisfy all requirements in the most effective and efficient way. The methods available to plan and accomplish these tasks are as vary as much as the tasks themselves. They range from job shop techniques to Material Requirements Planning (MRP) to Project-Based Management Information System (PBMS) to continuous manufacturing. This paper is a critical analysis aimed at classifying two of these system approaches as they relate to the ship repair equation.

Material Requirements Planning (MRP I) tracks a need for material through a project. The production process on the material determines how labor is applied to transform raw materials into finished products. MRP material needs are determined by sales forecast ing. while labor requirements are determined algorithmically from material take-offs. Another form is Manufacturing Resource Planning (MRP II). This form of MRP is a management process, supported by computers, which results in monthly production plans based on sales outlooks, etc., and is far more comprehensive in scope and integration than MRP I.

A complete Project-Based System incorporates the five phases inherent to any project. They are: organize, plan, implement, monitor, and control. The tools necessary to accomplish each of these phases are the heart and soul of a complete project-based Management Information System (MIS). This system approach uses labor as the functional attribute of the work, and ties material, required tools, references and other necessary items to each step of labor.

While both MRP and PBMS have their places in the industrial world, an analysis of the operational capabilities of each is necessary to determine which management system approach suites for the specific application of ship repair. After a detailed analysis of the needs and requirements of the ship repair industry, it becomes clear that a project-based MIS lends itself more closely to the operational requirements seen in the shipyard environment.

A discussion of how and when each type of system would be effective follows. The discussion will include a detailed breakdown of the basic concepts inherent in a PBMS as they relates to ship repair.

To date, most management systems developed revolve around the manipulation of accounting data for delivering processed information to managers. From this data, working decisions are made.

The new generation of project-based management systems, including those in the development phase, use a new index-basing concept. This new concept focuses on all aspects of the organizational and work structure. Only after complete definitions of these structures are defined. and are understood in a meaningful context, can the job requirements be assigned meaningfully and productively to the organization. Information tools are then used for effective execution of the job from a management or production control perspective.

Once the definition of reference structures is accomplished, the next task within this index-based management information system is the connecting of the structures. This is necessary so information can be "hooked" and coordinated into a viable plan for job understanding and later accomplishment. Development of these tools is explored in depth to show the inherent parts from which the PBMS model is derived. The study of structure development and interrelationships, and how the structure is independent of data, are dealt with in conceptual terms. Then, the uses of structures to form a computer-based information system is described.

In conclusion, the case is made for use of a project-based/index-based MIS in all phases of the ship repair industry. Versatility and adaptability are put forth as system attributes which make it an attractive alternative for any management application.

Productivity in the Shipyard Environment

Improving productivity in the shipyard environment can be one of the most challenging management problems. Developing the correct type of management system to deal with the productivity problem is the basis of this paper. This includes, how to do the most with the least, or how to balance customer demands against a limited work force and tight, budgets caused by heavy competition.

To achieve the optimal productivity from a production department there are certain key factors that must be present. Some of these factors are directly controllable and some are beyond the manager's control. The goal must be to handle all factors within the manager's control and reduce the effect of the factors over which he has no control. Productivity involves getting the most work possible out of an organization while maintaining a high level of morale. It also involves continually improving processes to promote the highest quality output.

To maintain a production base. management must make certain decisions about how much work the production work force can accomplish. Sometimes management's expectations of productivity can exceed the maximum productivity achievable. When this occurs production managers must decide how to handle the situation. If the work requirements are temporary, then temporary labor may be part of the solution. In contrast, if the work requirements are going to be a long term, then hiring new employees to fill the requirements may be the answer. In either case there are certain unknowns introduced into the production management equation. One unknown is the real capabilities of the new employees. This can obviously range from marginally capable to highly capable. The manager must then increase the use and productivity of the base work force, while reducing any negative impact resulting from the newly hired employees.

The Management Challenge

The complexity of ship repair and modernization work hinges on the large numbers of interrelated tasks that must occur in the proper sequence. Maintaining an entire work force that is

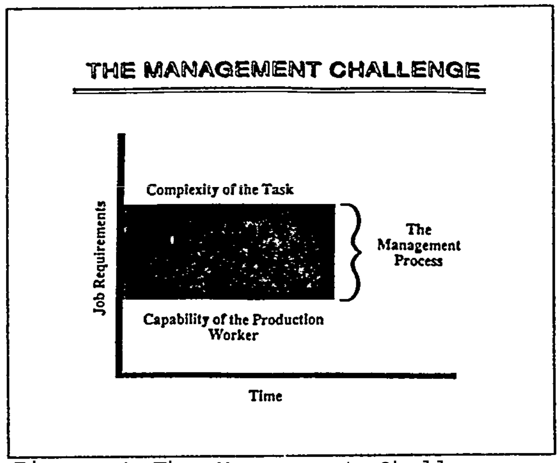

Figure 1 The Management Challenge

up to date in modern equipment and procedures is a very difficult task. To handle this problem the manager must develop a way to convey the requirements of the job in a form that everyone can understand. Those aspects of the job which are truly the responsibility of management (and not production) must be accomplished correctly before the assignment and execution of waterfront production work. Figure 1 graphically describes the Management Challenge. Management exists to- "close the gap" between worker capabilities and job complexities. Training and automation are only partial solutions. Computers can help in the process but can be an obstacle if improperly employed. Traditionally, most of the expertise that enables the manager to close this gap is gained through experience from years of on-the-job training. What will happen when the seasoned manager leaves the company through attrition or retirement? If he has done his job, there should be a long list of managers ready to take his place. This is not always the case and the company can suffer if this legacy degenerates. One way to capture this expertise and maintain the years of experience without being dependent on any one manager, is through the creation of an "Expert System". The following paragraph describes the positive and negative attributes of the "Expert System" concept as it relates to the ship repair equation.

The Expert Svstem[1 2]

Expert systems have been under development in some form since the early sixties. The expert system itself has developed as a branch of science dealing with artificial intelligence. Artificial Intelligence (AI) is the field of science dealing with the production of computer software. The software will emulate the thought processes of the

human brain. As one can imagine, the complex nature of brain processes pose a large problem for program developers.

An expert is a person who has in-depth knowledge of a subject. He has an in-depth understanding of all of the technical information dealing with the Subject. In the terminology of AI, a person with a strong knowledge of a specific area is the *"domain expert."* The expert has the ability to manipulate all of the data and information in a way to formulate an answer to the problem. By going to an expert you can get a quick answer to your problem. He can provide the information that you need, or get a quick solution for a difficult decision. The expert has gained his knowledge and experience through formal and informal learning as well as experience.

The ship repair industry uses experts in the field help to overcome the difficult and costly situations which impede production. Capturing the knowledge of these experts into a software program, and maintaining that knowledge has significant dividends both for the production effort as well as the training and development of future experts.

The additional benefits of expert systems are far reaching. *Improved productivity* is realized through the use of expert systems. This is realized by putting valuable knowledge at the manager's fingertips so it may be applied when needed. Thus, helping to get the job done more quickly and permitting the accomplishment of more work in the same time frame. The ability to *Preserve valuable knowledge. is* another benefit of Expert Systems (ES). The knowledge of an expert *is* extremely valuable. In most cases it has taken a long time and a lot of effort to accumulate the vast expertise in his field. It is very difficult to price the value of expert advice but, it proves invaluable when used. Packaging the expert's knowledge into a software program can result in a competitive advantage of great benefit in the ship repair industy. A third benefit is, *improved understanding and learning. The* expert system helps managers understand how the expert goes through the decision making process or how his knowledge applies to the problem. The use of expert systems on a regular basis by the manager will allow the manager to become quite familiar with the subject matter. If the manager realizes enough experience through the use of the system, the manager's performance may approach that of an expert.

Knowledge is the heart of all expert systems. Knowledge is the human understanding of a field of interest that is obtained through education and experience. Knowledge is structured information. The relationships between ideas, concepts, facts, figures, theories, procedures is knowledge. Much of the information that experts formulate into knowledge comes directly from a reference book. Examples of information are specialized material properties, math tables, and even a dictionary. By formatting and combining these types of knowledge, an expert system is created. This type of system would not provide the most valuable type of knowledge that the expert could provide. The expert provides *heuristic knowledge,* defined as a practical real-world understanding acquired through years of experience and exposure to many situations and problems.

Information and knowledge should not be confused. The two are used interchangeably but the differences are important. Information is uninterpeted data. Knowledge, on the other hand, is an understanding of the information based on analysis, a realization of its importance, and its applications. Later in this discussion, the use of knowledge vs. information, in developing index based management systems will become clear. The ability to represent the knowledge of the ship repair process in a knowledge base is the most difficult problem for the ship repair manager and system developer.

The field of expert system computing uses a totally different approach to computing than conventional approaches. The system starts with a knowledge of the domain. This knowledge once collected. represented, and stored in a form that a computer can readily use and understand. *This* knowledge is represented symbolically. A symbol is nothing more that a word. letter. or number used to represent objects, actions, and their relationships. The computer stores these symbols as ASCII strings. The interrelationship of information, as defined on the symbols represents the *knowledge base.* Once the knowledge base is created then a means of using it is developed. This means is in a program called the *inference program or inference engine. This* program is used to decide and make judgments based upon the symbolic data in the knowledge base. The inferenceing program takes external inputs about the problem and applies the available knowledge to arrive at a solution. Used in combination the knowledge base and the inference program are an expert system.

TWO APPROACHES CURRENTLY EMPLOYED FOR PRODUCTION MANAGEMENT SYSTEMS

Two of the diverse system approaches now employed as production management systems in today's ship repair industry, are Project Based Management Systems (PBMS) and Material Requirements Planning (MRP). MRP is a system based on material to which labor applied to manufacture an end product. PBMS uses labor and applies material as necessary to meet the job requirements. In the following paragraphs both types of management systems are discussed.

Material Requirements Planning (MRP)

Material Requirements Planning is a management system that develops the requirements for end products from sales orders and forecasted sales. The system then generates the requirements for the order of raw materials to accommodate the production processes necessary to form the end product. Throughout the production process, from ordering and receiving material to shipping the end product. labor is "tied to material". The demand for the end product initiates a long chain of events necessary to get parts to assemble the end product. The end product, composed of assemblies, which themselves are composed of sub assemblies are joined to form one product. The lead time requirement to order and receive these assemblies is a major part of the calculations necessary in the MRP system.

Material Requirements Planning calculations begin with the *master production schedule* which includes the number of units of each finished product produced in each period. With the information in the master production schedule, one can show when the various parts that make up the final product must be available. The master production schedule receives inputs from sales orders and forecasts. Once the parts are identified a *Bill Of Material (BOM)* is generated. The bill of materials is a structured parts list; however, it differs from an ordinary parts list in that it shows the hierarchical relationship between the finished product and its various parts. A schematic diagram of an MRP information system is shown in Figure 2. Forecasts and orders are used to develop the master production schedule. The master production schedule, Bill Of Materials, and current inventory files are the inputs to the MRP computations.

The output from the MRP computer program is the requirements for each item in the bill of materials along with the dates each item should be available. This information is used to plan order releases for production and purchasing. While the computations for MRP are very extensive, the development of high speed computers has facilitated its usage and development.

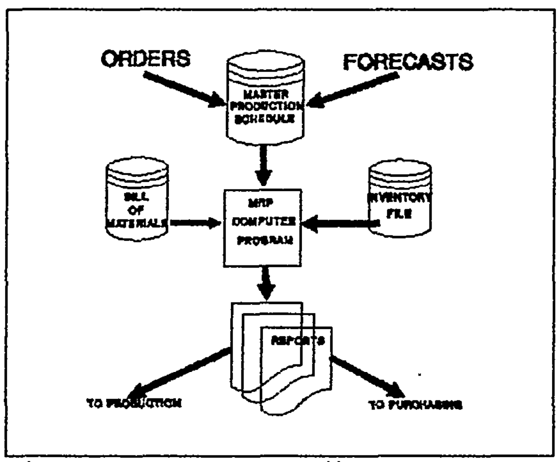

Figure 2 MRP System diagram

Project Based Management Systems (PBMS)

In contrast to the MRP system described above the PBMS uses labor and ties material to the labor element. To implement the PBMS a complete work breakdown structure must be organized and developed. A work breakdown structure consists of an organized approach to doing the job at hand.

One complete description of a PBMS starts with a description of the five (5) basic phases of any project. These phases are organize, plan, implement, monitor, and control. Using these five steps as an outline for the discussion

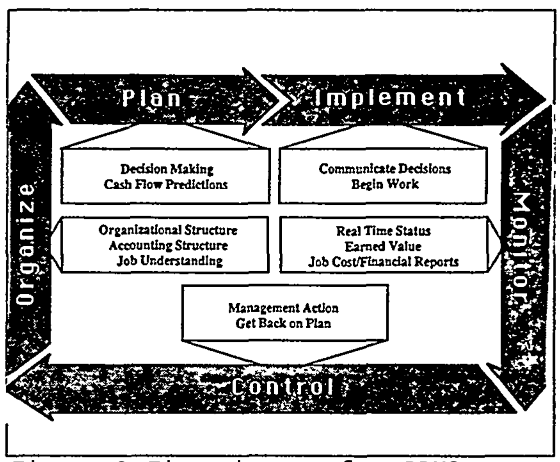

Figure 3 Five phases of a PBMS

of PBMs will show how the system is utilized. Figure 3 graphically represents the five (5) phases included in the PBNS.

Organize

The organizational phase is the most important of the five phases. During this phase, the project is broken down into small, understandable parts called *work elements* thoroughly to understand its scope. Figure 4 shows the work element definition and contents. Work elements are single trade/single operation steps of work. The trades and operations are based on the type of organizational structure and the desired level of managerial detail. The PBMS allows the task to be broken down to single trade - single operation level of detail and tie material and other supporting attributes to each work element. The pay-back of this approach is not only through a Greater understanding of the work, but also later in the management cycle. During the implementation phase. work tasking s made clear and understandable. During the monitoring phase of the project, consistent status information is available to make decisions.

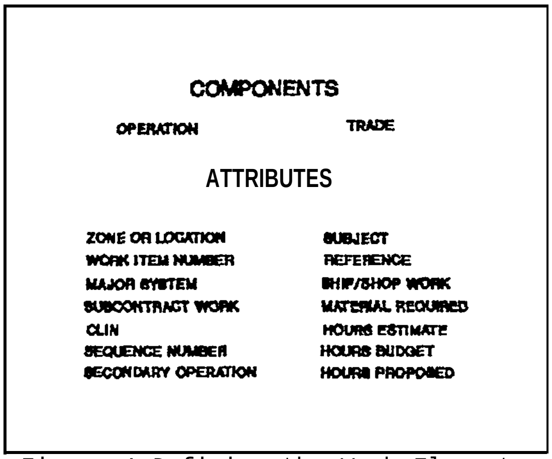

Figure 4 Defining the Work Element

Plan

The planning phase involves decision making regarding the who, when, and how work is to be performed. Using the database established in the organizational phase, one can view the scope of the job from many different perspectives to develop logical work packages. Figure 5 shows the various ways to look at work organization. Work packages are developed by trade/functional discipline, customer work item, zone, or type of work operation. "Do-able" work packages are created for production, which include all material, references, schedule, and resource information needed to do the task. Figure 6 describes the work package content. PBMS supports the application of group technology in the development of work packages while yet satisfying the progress reporting requirements of the customer. A master schedule is developed for work package starts and completions on an interactive basis to develop a satisfactory fit between customer milestones and labor resources.

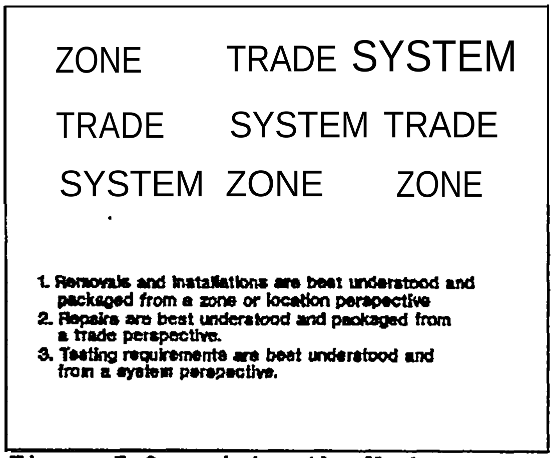

Figure 5 Organizing the Work

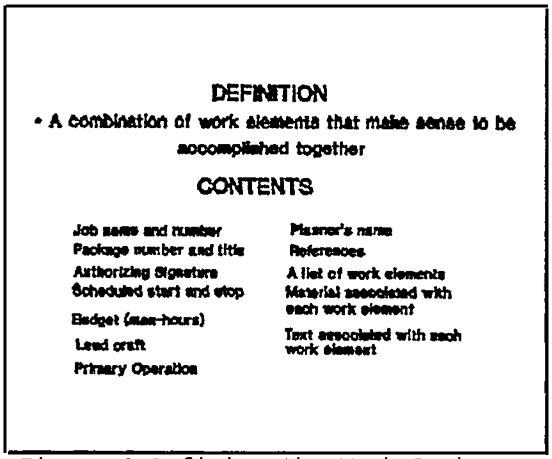

Figure 6 Defining the Work Package

Implement

Once scheduling of the Work Packages within the project and organizational guidelines is complete, the project manager is ready to implement the plan. Within the PBMS approach, implementation is a matter of communicating the plan to the functional organization for accomplishment. The project manager communicates the big picture for the project by milestone schedules as well summarized and detailed reports developed from the database. The project manager authorizes the expenditure of funds and communicates the job

funds and communicates the job requirements directly with the release of work packages to production. This is in accordance with the master work package schedule developed in the planning phase of the project cycle. PBMS work packages lend efficiency to this phase of the project because of their makeup and because the production workforce is freed from the material expediting, reference hunting, and production planning. tasks that have already been completed in an earlier phase. Rather. the production force can pursue quality workmanship and schedule satisfaction in accordance with the plan.

Monitor

Monitoring a project is a matter of obtaining timely and accurate work progress information. The monitoring base or budget is established in the organizing phase of the project. Assuming a detailed bottom-up budget was developed for each element of the customer's work requirements, a detailed earned value report by functional organization, customer work item, work operation or work zone/location can be generated. Information is generated at the lowest level of detail for analytic purposes or rolled up to higher summary levels for critical management and customer reporting. The basis for monitoring job progress is at the lowest level, the work element level.

Control

Project control requires management action. The PBMS can provide the tools for information processing, exception reporting and fault isolation. To a significant degree, identification of off-norm or out of control conditions to the responsible functional managers will make the project self-regulating. The database developed during the organizational phase contains so many key attributes, the PBMS provides a strong capability for "what-if" scenario analysis. The PBMS is totally integrated and has accessibility throughout the company so everyone is looking at the same information, thereby improving communication. Functional managers can then focus their attention on problems. If necessary thet can take appropriate management action to develop recovery plans to get back on track. This is done without significant input from the project manager. Significant problems can are analyzed and solution scenarios established quickly by the management team, since everyone is reviewing the same data.

COMPARISON OF MRP AND PBMS IN SHIP REPAIR

Both of the management systems described above have their place in business. To show which one is right for the ship repair industry a look at the industry itself is necessary. The repairs made to a ship during one overhaul probably will not occur exactly the same way, if at all, again. The repair is often a one time event in the life of the ship. Also. in general the basic repair job consists of at least 60% labor (and 40% material). It would not be logical to process material as the guiding component in the management system decision when it constitutes only 40% of the repair job. The more logical path is to tie material to the labor portion of the job. The PBMS also provides tools for managing people, and not treating the human component as secondary to the product. PBMS considers material as a tool, however essential, and necessary it is to complete the job. Material is procured as a necessary resource, ordering by lead times for timely delivery to support a process conducted by people (labor).

With the MRP methodology a repetitive cycle of like events and parts is necessary to realize the full benefit of the management system. The MRP system is better suited to a pure manufacturing process due to the repetitive nature of the process itself, while the PBMS is better suited to the shipyard environment.

INDEXING AS AN ORGANIZING TOOL

Considering that PBMS are the most feasible systems to use for the ship repair management system, there are several options that are making the PBMS even easier and more attractive for the repair activity. Indexing has shown itself as a viable organizing tool for many applications. Its adaptability and flexibility make it a very good tool for organizing work in the PBMS arena.

Indexing is the way to apply the "expert system concept" to the ship repair problem without the large investment of time and sometimes unpredictable results of the classical expert system. Developing the index through use of expert relations allows the nodes of the index to be associated in a "smart" fashion.

Development of Structures

Large amounts of data manipulation have been one of the important thing that computers can accomplish. They are capable of manipulating and performing computations to data to show any of the information that the operator needs to

know. In today's era of computing, data manipulation is still important. What is more important is the way in which the data is organized. Organizing the structure of the data is where indexing will dramatically change the approach to management and computers in industry. Indexing is a fast and simple way to set up hierarchical structures to capture relationships. It allows the manager to adapt the organization to changing environments, different business climates and resource levels without expending the time and expense in the hard coding of database management systems and application programs.

The index system should not be confused with database management systems. There are distinct differences. A database management system allows the user to create and manage large files of data. It is often confused with a knowledge base. A database comprises small units of data called records, which comprise individual data elements called fields.

While a record is a unit of data containing facts and figures rather than knowledge, a knowledge base comprises individual chunks of knowledge. One basic form of representing knowledge is a *rule.* A rule describes the outcome of processing data. Another confusion of databases and knowledge bases is the way the programs search the bases to arrive at the desired end product. A database searches the records to arrive at a certain specific item, often with one or more common elements. The search of a knowledge base is conducted to link units of knowledge to form a logical chain of inferences duplicating human reasoning. The output of the database is usually a set of records to which further analysis must be done to define a rational path of action or a decision. The knowledge base and inference pragram's output is supposed to represent the rational path of action or decision without further analysis.

In the world of indexing, there are several terms that require definition before a complete understanding of the entire process is achievable. There are two basic types of indices. The first is the reference index. Its function is to describe the organization of any hierarchy in any business or process. Picture an organization chart of a company as an index with the CEO at the top of the structure and then working down through the organization. The reference index is the most critical of the indicies. They are use by the manager as reference structures to develop a context for job understanding and to develop the second type of index, the variable index. The information contained in the structure of the reference index often serves as the template for the structure of the variable index. It can be a representation of an organization, or a process. The reference indices are maintained by the cognizant individuals in the corporate organization (i.e.. the personnel reference index will be maintained by the personnel manager). Development of the reference indices is how expert system concepts are implemented into the index. All of the relationships of the nodes within the reference indices can be created with expert relations, thus making the reference index a smart index. In this way. the vast knowledge of seasoned shipyard veterans is saved for future use.

The second type of index, the variable index, is the working tool of the manager. Using the reference index as the basis, the manager develops the variable index to fit the requirements of the job at hand. This could be anything from setting up a job to Setting up a structure for a report that used for customer cost reporting. This method of organizing uses several tools to accomplish the development of the variable structure.

The first tool is the "link". The link is the tool which ties a node of reference index together with a node from another reference index to form the variable index. The method of linking is an interactive operation. It can be thought of as a transaction or a bond between the two nodes within references indices. In the PBMS world, development of a work breakdown structure (WBS) would involve linking of a trade or craft of the "personnel reference index" to an operation of the "operation reference index". The link would then hold knowledge that the specified trade will perform the selected operation. This link would form the initial bond to organize the entire work breakdown structure. Links to other installed reference indices would facilitate the completion of the WBS. Other indices which could be part of the reference index library would include but not be limited to the "configuration", and "process". The configuration reference index would contain the entire configuration of the ship type that under repair. It would be a breakdown through a hierarchial structure of every piece of equipment right down to the part level. Each of the parts would have associated with it all the identifying data needed to order or replace any piece as deemed necessary. This index would be self-maintaining once entered. Each time a new part is added such as an alteration addition, the part or assembly is entered into the configuration index. The process index would be a work flow diagram of all the

work to he performed. It is basically a template to which the manager can link other reference indices to add trades, operations. and configuration information to the job changes during the production implementation process.

The next tool needed is the "hook". A hook is used to retrieve data elements of a database and for use in the application of the structure. The data that the hook would retrieve would be the variable data on a job such as "hours charged". The data is updated through the various update methods in place to perform these functions, also organized by the index.

The final part of the index system is the inferencing program. This program is independent of the reference or variable indices. This allows an index to change without affecting the way any inference program delivers its output. The inferencing program would only reference the index's top level and then proceed to search the index for the applicable node which contains the information that the inferencing program requires. The ability to change the structure of an organization or process and still maintain the ability to use the same application programs is a new advancement in the MIS world.

Control and Flexibility

The index system as an organizing tool is the most versatile and flexible yet in the field of front end systems to large project management systems. The managers ability to change. reorganize, and alter the structure of the organization without destroying the capability of the downline managers to do their job within the system is now within reach. The ability of the manager to control the structure of the organization in a real time mode has not yet been realized in the marketplace. Seldom has such a revolutionary scheme been introduced into the management world. In the past and perhaps in other organizations, the ability to make changes to the installed management system is dependent on the ability of the programmers to reprogram the hard coded application programs. This process is time consuming and is fast becoming outdated. The index will soon replace many programmers in corporate programming departments.

Innovations in the hardware and software world have made the index a viable reality. In the past, speed and size restrictions were placed on the capability of an application such as the index system. Today those limitations no longer exist. The structure size is only limited by the computer's internal memory and is seldom a consideration.

The graphics interface that the index system uses makes it user friendly and adds the ability to change the system online.

In Conclusion

The PBMS is the best solution to the management system problem within the shipyard environment. Its ability to facilitate the organization, planning, implementation, monitoring and controlling of the ship repair problem is the key to improving productivity. The extra effort spent in orgainzing the work in the planning phase is more than recouped in the production phase through increased productivity due to better job organization through better job understanding.

The flexibility of the indexing system allows it to be used as the front end processor, not only on project systems such as the PBMS but also on accounting, personnel, and procurement applications. It has shown itself as a viable too1 for organizing just about any function currently used in any organization. The adaptability allowed by creation of the reference indices to suit the operations will allow the index based management information system to be used throughout the spectrum of applications within the corporate world.

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24,1990

Shipyard Skills-Tracking System 3B-1

John Walker Hartigan, NAVSEA, Washington, DC

The naval shipyards are in the process of installing a system for identifying and recording specific job -related skills in their industrial workforce. The system, called the Shipyard Skills Tracking System (SSTS), is intended initially to support middle-level management in allocating their workforce properly for critical tasks and in accurately facforing personnel availab*ility and training requirements into the planning for upcoming work. SSTS is supported by sophisticated computer programs which are integrated into other shipyard administrative programs. Data entry, ever the bugaboo of large scale tracking programs, is minimized by using data links to other job related programs for most of the information. The programs have been successfully field-tested at one naval shipyard and, starting in* November 1989, began *undergoing phased installation at all eight government yards.*

You are a newly-appointed general foreman in the pipe shop at the (mythical) San Jose Naval Shipyard. Having arrived at NAVSHIPYD SJOE only two weeks ago, you are not yet fully familiar with the capabilities and qualifications of the personnel in your shop.

You answer the phone. It is the head of a NAVSHIPYD SJOE "tiger team" that is performing repairs on a submarine in Heavy Loch, Scotland.

"You gotta help me! We need a pipefitter over here right away! We need somebody who can do a battery replacement, and it's got to be someone who can take the lead on the job."

Who can you send? Which of several hundred people in the shop has the necessary skills and experience to do the job? You remember overhearing someone in the shop mention that Jim Smith had worked a battery replacement job. But how long ago did he do it? And how good is he? Is he capable of serving as the lead mechanic on the job at Heavy Loch?

There are additional questions you need answers to, and not much time to get them. Is Jim Smith available to go to Heavy Loch for three weeks or more? To be sent immediately, he will need a passport: does he have one? Is it current? What formal qualifications are needed to perform a submarine battery replacement? Are Jim Smith's qualifications current, or have they **expired,** and, it they have, which ones will require that he be retrained and which that he be re-tested without additional training? And, perhaps the most important questions: is Jim Smith the best mechanic to send on this job? or are there others in the shop who are equally or better qualified?

Supervisors and managers in the naval shipyards now have a system that can answer all of these questions and more: the Shipyard Skills-Tracking System (SSTS). Today, using SSTS, you, as the general foreman with the battery-replacement problem, simply turn to the microcomputer on your desk and request a list of all mechanics in your shop who have accomplished a battery replacement successfully. In a few seconds, the computer displays a list of those mechanics, including how many times each of them performed the job, how significant their contribution was to its completion, and how recently they performed it. Based on this information, you are quickly able to identify those mechanics who are most skilled at battery replacement and to assign one to the job.

Generations of foremen and general foremen in the naval shipyards have dealt with such questions by simply remembering, as best they could, who in their work gangs and shops possessed special skills and experience. Often they kept informal records in hip-pocket booklets. But today's ships are too complex for that to be feasible any longer. Much of the work on nuclear submarines and surface ships with sophisticated combat systems requires that the mechanics assigned possess formal qualifications for performing it--too much of the work and too many qualifications for any manager to keep in his or her head. And many shipboard systems are too sensitive to error to risk assigning mechanics who are not fully competent to perform the required work correctly-the consequences of error can be expensive rework or harm to the ship or its personnel.

In recent years, many shipyard production shops have tried to systematize the collection and maintenance of' data on the special qualifications and skills of their personnel. The results of such efforts were known variously as "skills banks" and "skills inventories." Some shops were successful in the initial establishment *of* their banks or inventories, only to find themselves unable to keep them current

as their workers acquired new skills, lost skills through disuse, transferred, and retired. But, as was stated in 1988 by Dr. Amiel T. Sharon, “The increasing complexity and sophistication of industrial equipment, processes and systems creates a demand for specialized maintenance skills that require extensive training and experience. Consequently, to use its personnel effectively, an organization must have up-to-date information on its individual employees’ capabilities”(l).

At a conference in 1985, the Naval Sea Systems Command (NAVSEA)‘s Training Information Resources Office (TIRO) stepped into the breach. Representatives of seven of the eight naval shipyards asked NAVSEA to develop a skills-tracking system that could be used by the production shops in all yards: TIRO was assigned to develop the basic specifications for such a system and to manage its development and implementation.

TIRO’s design of what has become the Shipyard Skills-Tracking System (SSTS) benefitted from an advantage not enjoyed by previous generations of skills-bank designers: the advent of the microcomputer, and the ability that microcomputer technology affords for keeping data reliably current.

SSTS is an on-line automated data-processing system that identifies those workers who are experienced and qualified to perform critical, complex, difficult, and hazardous tasks. SSTS accomplishes this by tracking workers’ nuclear, radiological-control (RadCon), and submarine-safety (SubSafe) qualifications and any other skills and qualifications they possess that a shop chooses to track. SSTS also monitors employee training records and shop work experience. The system provides supervisors and managers with immediate and current data on workers’ qualifications and requalification status, enabling them to assign the qualified personnel with the best experience to complex and critical jobs.

SSTS is an Integrated Data Store II (IDS-II) database system that is accessed through Transaction Processor 8 (TP8), COBOL-74 transaction-processing routines (TPRs), and 3270-protocol communications. SSTS resides on a naval shipyards Honeywell mainframe computer. The system can be accessed from any terminal or microcomputer that can communicate via 3270 protocol with the Honeywell mainframe. This feature permits a ship yard supervisor or manager to use SSTS to check workers’ skills and qualifications, to input time and attendance data via the Automated Time and Attendance Muster System (ATAMS), and to check on the status of work materials through the Material Management (MM) system, all from the same terminal or microcomputer.

An important feature of SSTS is that it runs on existing computer hardware --no new equipment had to be bought on which to run SSTS.

The currency of data in SSTS is maintained through interfaces with other shipyard standard and local mainframe, mini-, and microcomputer systems, such as the Shipyard Management Information System (SYMIS) payroll application and the Automated Radiological Control Management information System (ARCMIS).

The supervisor or manager using SSTS gains access to the data he or she needs via a series of screen menus that guide him or her to the desired report screen. Some of the information available on these report screens includes:

- Requalification dates (see figures 1 and 2). This report is produced in date sequence and can be provided on all workers in the entire shipyard, on an individual shop’s workers, on workers assigned to a specific supervisor, on an individual worker, or on an individual qualification.
- The qualifications needed by a worker to perform a particular job (see figures 3 and.4). Qualification requirements are defined at the job, duty, task, and subtask levels.
- A list of the names of all workers experienced in application of a particular skill. This report can be provided to identify all workers with the skill in the entire shipyard or only those in a specific shop or trade (see figures 5 and 6), or only those assigned to a particular supervisor, or only those who possess a specific attribute, such as a current passport or willingness to work at remote job sites (see figures 7 and 8). Figure 9 displays the screen report of all of the attributes that one of the naval shipyards has chosen to track and on which SSTS will provide information.
- Skills possessed by a specific worker (see figures 10 and 11).
- An individual worker’s attributes (see figures 12 and 13).
- Secondary skills. These are skills a shipyard may want to call on a worker to employ when workload is temporarily light in the worker’s trade. SSTS provides reports of the secondary skills currently being tracked by a shipyard, of all employees who possess a specific secondary skill (by supervisor, by shop, or for the entire yard), and of the secondary skills possessed by a specific worker (see figures 14 and 151.

SKILLS TRACKING SYSTEM
MENU FOR REQUALIFICATION DATES

ENTER SHOP: **

ENTER PARAMETER DATE: 06/01/92 (MM/DD/YY)

ENTER SUPERVISOR CODE: 43
(IF DESIRED)

ENTER QUALIFICATION: AIR-FED RESPIRATOR******
(IF DESIRED)

THE PARAMETER ENTRY LIMITS THE REPORT SCREEN TO
REQUALIFICATIONS NEEDED PRIOR TO THAT DATE

PRESS ENTER TO PROCESS TRANSACTION OR ENTER AN "X" TO EXIT TO QUERIES MENU:

Figure 1. MENU FOR REQUALIFICATION DATES

SKILLS TRACKING SYSTEM
REPORT OF REQUALIFICATION DATES

SHOP: 56	BADGE	PAY	SHIFT			REQUAL
EMPLOYEE NAME	NUMBER	GRADE		SUPER	QUALIFICATION	DATE
JOHNSON, C,	238749	WG-10	1	43	AIR-FED RESPIRATOR	01/15/91
MAXWELL, s.	312647	WG-05	1	43	AIR-FED RESPIRATOR	03/23/91
FELLOWS, E.	265439	KG-05	1	43	AIR-FED RESPIRATOR	03/10/91
ADAMS, L.	135243	NG-10	1	43	AIR-FED PESPIRATOR	03/10/92

PRESS ENTER TO DISPLAY NEXT PAGE OR ENTER AN "X" TO EXIT TO REPORT MENU:

Figure 2. REPORT OF REQUALIFICATION DATES

SKILLS TRACKING SYSTEM
MENU FOR QUALIFICATIONS NEEDED TO PERFORM A SPECIFIC SKILL

ENTER SKILL SHOP: 56
AND
ENTER SKILL CODE: 0B0105
OR SKILL DESCRIPTION: ***************

PRESS ENTER TO PROCESS TRANSACTION OR ENTER AN "X" TO EXIT TO QUERIES MENU:

Figure 3. MENU FOR QUALIFICATIONS NEEDED TO PERFORM A SPECIFIC SKILL

SKILLS TRACKING SYSTEM
REPORT OF QUALIFICATIONS NEEDED TO PERFORM A SPECIFIC SKILL

SKILL SHOP: 56 SKILL CODE: 0B0105 SKILL TYPE: OT

SKILL DESCRIPTION: BATTERY REPLACEMENT

QUALIFICATIONS: BATTERY SAFETY
RESPIRATOR

PRESS ENTER TO DISPLAY NEXT PAGE OR ENTER AN "X" TO EXIT TO REPORT MENU:

Figure 4. REPORT OF QUALIFICATIONS NEEDED TO PERFORM A SPECIFIC SKILL

```
                SKILLS TRACKING SYSTEM
      MENU FOR EMPLOYEES EXPERIENCED AT A SPECIFIC SKILL

ENTER SKILL SHOP:       56
AND
ENTER SKILL CODE:       ******
OR SKILL DESCRIPTION:   BATTERY REPLACEMENT*******

ENTER SUPERVISOR CODE: **
                        (IF DESIRED)

ENTER OCCUPATION CODE: ****
                        (IF DESIRED)

ENTER UNIQUE ATTRIBUTE:      ***********************
                        (IF DESIRED)


PRESS ENTER TO PROCESS TRANSACTION OR ENTER AN "X" TO EXIT TO QUERIES MENU:
```

Figure 5. MENU FOR EMPLOYEES EXPERIENCED AT A SPECIFIC SKILL

```
                SKILLS TRACKING SYSTEM
     REPORT OF SHOP EMPLOYEES EXPERIENCED AT A SPECIFIC SKILL

SKILL SHOP:56         SKILL CODE: 0B0105     SKILL DESCRIPTION:BATTERY REPLACEMENT
          SKILL TYPE:OT     UNIQUE ATTRIBUTE:  NOT REQUESTED
```

EMELOYEE	BADGE NUMBER	TRADE	SHOP	PAY GRADE	SHIFT SUPER	QUAL	SKL LEV	TIMES PERFMD	DATE LAST COMPLETED
ADAMS,L.	135243	PIPEFITTER	56	WG-10	1 43	RS	1	007	05/10/88
FOX, J.	247431	PIPEFITTER	56	WG-05	1 23		5	001	05/10/88
OLSEN,D.	354352	PIPEFITTER	56	WG-08	2 29	S	2	005	11/15/89
SMITH,J.	786503	PIPEFITTER	56	WG-10	1 43	NRS	1	004	11/15/89

```
PRESS ENTER TO DISPLAY NEXT PAGE OR ENTER AN "X" TO EXIT TO REPORT MENU:
```

Figure 6. REPORT OF SHOP EMPLOYEES EXPERIENCED AT A SPECIFIC SKILL

```
                SKILLS TRACKING SYSTEM
         MENU FOR EMPLOYEES BY UNIQUE ATTRIBUTE

ENTER UNIQUE  ATRIBUTE:     SAN DIEGO *****************k*

ENTER SHOP OR "XX":     xx

ENTER SUPERVISOR CODE: **
                        (IF DESIRED)

PRESS ENTER TO PROCESS TRANSACTION OR ENTER AN "X" TO EXIT TO REPORT MENU:
```

Figure 7. MENU FOR EMPLOYEES BY UNIQUE ATTRIBUTE

SKILLS TRACKING SYSTEM
REPORT OF EMPLOYEES BY UNIQUE ATTRIBUTE

UNIQUE ATRIBUTE: SAN DIEGO

EMPLOYEE NAME	BADGE NUMBER	SHOP		PAY GRADE	SUPERVISORS NAME
ADAMS, L.	135243	PIPEFITTER	56	WG-10	JONES, J.
FOX, J.	247431	PIPEFITTER	56	WG-05	SIMMONS, R.
OLSEN, D.	354352	PIPEFITTER	56	WG-08	HANKS,A.
SMITH, J.	786503	PIPEFITTER	56	WG-10	JONES, J

PRESS ENTER TO DISPLAY NEXT PAGE OR ENTER AN "X" TO EXIT TO REPORT MENU:

Figure 8 REPORT OF EMPLOYEES BY UNIQUE ATTRIBUTE

SKILLS TRACKING SYSTEM
REPORT *OF* CURRENT ATTRIBUTES

PASSPORT
ALAMEDA
HUNTERS POINT
SAN DIEGO
GROTON, CT
OTHER USA LOATIONS
ROTA, SPAIN
OTHER OVERSEAS LOCATIONS
SEA TRIALS (SSN637)
SEA TRIALS (SSN688)
0. E. CLEARENCE
STE
FORK LIFT LICENSE
EMERGENCY RESPONSE TEAM

PRESS ENTER TO DISPLAY NEXT PAGE OR ENTER AN "X" TO EXIT TO REPORT MENU:

Figure 9. REPORT OF CURRENT ATTRIBUTES

SKILLS TRACKING SYSTEM
MENU FOR SKILLS PERFORMED BY A SPECIFIC EMPLOYEE

ENTER EMPLOYEE BADGE NUMBER: ********
OR
ENTER EMPLOYEE FIRST INITIAL: *
EMPLOYEE LASTNAME: ****************

PRESS ENTER TO PROCESS TRANSACTION OR ENTER AN "X" TO EXIT TO QUERIES MENU:

Figure 10. MENU FOR SKILLS PERFORMED BY A SPECIFIC EMPLOYEE

SKILLS TRACKING SYSTEM
REPORT OF SKILLS PERFORMED BY A SPECIFIC EMPLOYEE

EMP. NAME: SMITH, J.	BADGE: 786503	TRADE: PIPEFITTER
SUP. NAME: JONES, J.	PAY GRADE: WG-18	SHOP: 56 SHIFT: 1
NUCLEAR LEVEL: LIMITED	RADCON LEVEL: BASIC	SUBSAFEQUAL: YES
REQUAL. DATE: 01/15/91	REQUAL. DATE: 12/21/98	REQUAL. DATE: 10/14/90

LISTING OF SKILLS PERFORMED

SKILL SHOP	SKILL CODE	SKILL DESCRIPTION	TYPE	LEVEL	TIMES PERFD	DATE LAST COMPLETED
56	0A0107	ASW SYSTEM PIPING FLANGES	SS	1	006	12/19/88
56	0B0105	BATTERY REPLACEMENT	OT	2	004	11/15/89
56	0C1204	BUTTWELD JOINT MAKEUP	NU	1	024	07/20/89
56	0C1609	H.P. AIR SYSTEM VALVES	SS	1	024	08/18/89
56	0D0304	TRIM DRAIN FLANGES	SS	2	010	09/05/87
56	060903	DISTILLERS 2K-8K-16K GPD	OT	3	001	05/18/86
56	050204	FLEXATALILC FLANGE MAKEUP	SS	2	004	02/22/90
56	0L1002	FREEZE SEAL	NU	1	007	02/22/90
56	0M0304	RESIN FILL BEND	Nu	1	006	06/21/89
56	0N1103	SILVER BRAZE (NUCLEAR)	NU	1	024	04/14/88
56	0W201	WAVE GUIDE (FABRICATE)	OT	3	001	05/09/86
56	0W0301	WAVE GUIDE (INSTALL)	OT	3	001	06/03/86

PRESS ENTER TO DISPLAY NEXT PAGE OR ENTER AN "X" TO EXIT TO REPORT MENU:

Figure 11. REPORT OF SKILLS PERFORMED BY A SPECIFIC EMPLOYEE

SKILLS TRACKING SYSTEM
MENU FOR UNIQUE ATTRIBUTES BY A SPECIFIC EMPLOYEE

ENTER EMPLOYEE BADGE NUMBER: 786503
OR
ENTER EMPLOYEE FIRST INITIAL: *
EMPLOYEE LAST NAME: ****************

PRESS ENTER TO PROCESS TRANSACTION OR ENTER AN "X" TO EXIT TO REPORT MENU:

Figure 12. MENU FOR UNIQUE ATTRIBUTES BY A SPECIFIC EMPLOYEE

SKILLS TRACKING SYSTEM
REPORT OF UNIQUE ATTRIBUTES BY EMPLOYEE

EMP. NAME: SMITH, J.	BADGE: 786503	TRADE: PIPEFITTER
SUP. NAME: JONES, J.	PAY GRADE: WG-10	SHOP: 56 SHIFT: 1
NUCLEAR LEVEL: LIMITED	RADCON LEVEL:BASIC	SUBSAFE QUAL: YES
REQUAL. DATE.: 81/15/91	REQUAL. DATE:12/21/90	REQUAL. DATE: 10/14/90

LISTING OF UNIQUE ATTRIBUTES

PASSPORT
HUNTERS POINT
SAN DIEGO
FORK LIFT LICENSE
O.E. CLEARENCE

PRESS ENTER TO DISPLAY NEXT PAGE OR ENTER AN "X" TO EXIT TO REPORT MENU:

Figure 13. REPORT OF UNIQUE ATTRIBUTES BY EMPLOYEE

```
SKILLS TRACKING SYSTEM
MENU FOR SECONDARY SKILLS BY A SPECIFIC EMPLOYEE

ENTER EMPLOYEE BADGE NUMBER:      786503
OR
ENTER EMPLOYEE FIRST INITIAL:      *
      EMPLOYEE LAST NAME:    ****************

PRESS ENTER TO PROCESS TRANSACTION OR ENTER AN "X" TO EXIT TO REPORT MENU:
```

Figure 14. MENU FOR SECONDARY SKILLS BY A SPECIFIC EMPLOYEE

```
SKILLS TRACKING SYSTEM
REPORT OF SECONDARY SKILLS BY EMPLOYEE

EMP. NAME: SMITH, J.       BADGE: 786503            TRADE: PIPEFITTER
SUP. NAME: JONES, J.       PAY GRADE: WG-10         SHOP: 56 SHIFT: 1
NUCLEAR LEVEL: LIMITED     RADCON LEVEL: BASIC      SUBSAFE QUAL: YES
REQUAL. DATE: 81/15/91     REQUAL. DATE: 12/21/90   REQUAL. DATE: 10/14/90

LISTING OF SECONDARY SKILLS

AUTOMOTIVE TUNE-UP
PAINTING
SANDBLASTING
WELDING (NON-PRODUCTION)

PRESS ENTER TO DISPLAY NEXT PAGE OR ENTER AN "X" TO EXIT TO REPORT MENU:
```

Figure 15. REPORT OF SECONDARY SKILLS BY EMPLOYEE

In addition to the foregoing, SSTS provides reports on the workers who possess a specific attribute, on the qualifications that a yard is currently tracking, and on the skills currently being tracked by the yard. SSTS also provides reports on the number of employees, by pay grade, who possess skills being tracked by the system; reports on supervisors to whom personnel who possess tracked skills are assigned; and a report on the numbers of workers possessing tracked skills who are eligible to retire. This last report is by shop and projects retirement eligibility for the *next five years.*

SSTS was implemented between April 1989 and July 1990, and is now on line and in use in six of the eight naval shipyards. The system may be implemented at the Long Beach Naval Shipyard at some future date, but, because of workload and staffing considerations at that yard, there are no current plans to do so. Full implementation of the system at Mare Island is awaiting on resolution of some computer software incompatibilities

Not only does SSTS show how often and how recently a worker has performed a given job, it also indicates at what level the worker has performed it. Upon completion of a job, the supervisor indicates on the worker's time card (or equivalent record, where time cards are not employed), whether the worker performed at the "5" level (meaning the worker provided some assistance to a lead mechanic) or at the "1" level (meaning that the Worker performed the job independently or was its lead mechanic), or at a level between those extremes. The skill-level indication is not a performance rating but, rather, a guide for the supervisor and manager to use in making work assignments and in determining training requirements.

Determination of training requirements is one of the ways SSTS can be put to use beyond the shop floor. SSTS provides a tool for shipyard management to use in comparing projected workload with skills on hand. SST's reports can reveal skill shortfalls and point up where new training, hiring, or other workforce adjustments are needed to bring a shipyards skill mix in line with its workload requirements.

It should be emphasized, though, that SSTS is neither a training-management system nor a record of training undergone by workers. Training records indicate what training workers have received, but they do not necessarily show what work those workers are capable of doing. Unless a particular training course has included a requirement that its trainees demonstrate their mastery of specific job skills, it cannot be assumed that the course imparts the skills necessary to do the required work. Moreover, most work skills are learned on the job, not in the classroom, and so never appear in the training records. SSTS, however, documents skills that have actually been demonstrated on the job.

Because SSTS has been designed and programmed to run on the naval shipyards Honeywell computers, and because the system is dependent on interfaces with other naval-shipyard automated data processing programs, it cannot be exported to a private shipyard or other industrial enterprise and used as is. Two SSTS documents, the System *Files Update Users' Manual* (2) and the *System Files Queries Users' Manual (3)* could, however, be used as a guide to the architecture of the system by those interested in designing and programming their own skills-tracking systems.

Note

The names of workers and supervisors in the figures accompanying this paper are fictional, so that no privacy-act requirements have been violated; neither have any classified or "NOFORN" data been included.

Acknowledgments

The success of SSTS in getting off the drawing board and into the hands of shipyard users is due in large part to the energy and tenacity of Donald E. Cummings, Director of the NAVSEA Training Information Resources Office, who, as SSTS project manager, spearheaded its design and implementation. Programming, **testing,** *and loading of SSTS were capably managed by Donald Wamsley and Stephen Clements of the NAVSEA Automated Data Systems Activity (SEAADSA).*

The author was assisted in preparation of this paper by Lcdr C. Lee Walker USN (Ret).

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
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Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24,1990

Shipbuilding and the Malcolm- Baldridge National Quality Award 3B-2

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Abstract

This paper examines how shipyards in the U.S. can benefit from participation in the Malcolm Baldrige National Quality Award program. Although shipyards may be years away from meeting the criteria of the award, a long term plan to address these criteria will lead the yards to a more competitive position in the world. The Malcolm Baldrige Award is highly respected and is the highest level of recognition that a U.S. company can receive. The paper focuses on the application and examination of the seven categories of the Malcolm Baldrige Award selection criteria as they apply to shipbuilding. By using this structure, shipyards can greatly improve their management of quality. Ultimately, a shipyard that applies for and succeeds in winning the award would have a clear competitive advantage in the marketplace, both domestically and world-wide.

Introduction

The 1980s was a decade of change for U.S. shipbuilders. Subsidies disappeared; commercial orders disappeared: and the Navy became the only purchaser of U.S.-built ships. Many shipyards went out of business while those that survived modified their operations considerably by:

- Downsizing
- Renegotiating labor contracts
- Adopting advanced shipbuilding techniques promulgated by Japanese consultants and by the National Shipbuilding Research Program.

This new and improved U.S. shipbuilding industry has yet to prove itself in the commercial market and still carries a reputation with commercial operators for providing a marginal quality, high priced product in a too long total construction cycle time.

In the first half of 1990, global shipbuilding -demand has 'exploded due to higher freight rates; an aging fleet, improved economic conditions, and anticipation of stringent pollution regulations. Japanese shipyards have full order books through 1992; the Koreans are similarly booked: and the Europeans are getting more orders. Clearly, there is potential for U.S. shipyards to benefit from this market, and the technological and labor relations improvements of the 1980s. will contribute to U.S. yards' ability to market their product. However, there still remains the perception among ship owners that U.S. shipyards are difficult to work with and produce inferior quality ships.

To overcome that negative perception, U.S. shipyards have a number of options. This paper proposes the Malcolm Baldrige National Quality Award framework as one possible way for U.S. shipbuilders to improve quality and to communicate that improvement to their potential customers.

What is the Baldrige Award?

Malcolm Baldrige served as Secretary of Commerce from 1981 until his death in 1987 and contributed to long-term improvement in efficiency and effectiveness in Government. Congress passed the Malcolm Baldrige National Quality Improvement Act of 1987 (Public Law 100-107) to address the following issues:

- U.S. quality and productivity have declined relative to foreign competition
- U.S. businesses are only beginning to understand that poor quality costs companies as much as 20 percent of sales revenues
- Strategic planning for quality improvement programs is essential

- Quality improvement programs must be management-led and customer-oriented.

In creating the Award, Congress commissioned the National Institute of Standards and Technology (NIST) to administer the Award and to develop the evaluation criteria. The NIST found developing. the award guidelines quite challenging because it required:

- Defining what constitutes "quality"
- Measuring qualitative aspects of quality
- Maintaining flexibility in determining appropriate quality practices for different approaches (e.g., Deming, Juran, Crosby), industries, and company sizes.

Ultimately, the NIST came up with Award framework categories to emphasize management-driven, data-based, customer-focused, flexible, and continuously improving quality programs. The framework has seven categories, which are listed in Figure 1 with their corresponding maximum award point values. Three factors are used to evaluate a company's quality improvement efforts in each of the seven categories: approach, deployment, and results. Approach involves the degree to which the company's methods:

- Are prevention-based
- Are systematic, integrated, and consistent
- Embody self-evaluation, feedback, and adoption of cycles to sustain continuous improvement
- Are based on quantitative, objective, reliable information.

Deployment is the extent to which the approach is applied to all relevant areas and activities, including all transactions with customers, suppliers, and the public: all internal processes, activities, facilities, and employees; and all products and services. Results reflect the extent to which quality has been improved due to effective deployment of the approach.

The award creators addressed the issue of comparing companies in differing industries and of different sizes by offering six awards each year, two each to manufacturing companies, service companies, and small businesses. Once the framework and criteria were developed, reviewed, and revised by leading quality experts, the first applications were distributed in early 1988. In the first year, two manufacturers, Motorola and the Commercial Nuclear Fuel division of Westinghouse, and one small firm, Globe Metallurgical, won the prize. In 1989: the only winners were Milliken & Company and the Xerox Business Products Systems division. Clearly the award criteria are difficult to meet: only five of twelve possible awards have been captured in two years, and no service companies have won yet.

Figure1:

Baldridge Framework Categories

Leadership	100 points
Information and Analysis	60 points
Strategic Quality Planning	90 points
Human Resource Utilization	150 points
Quality Assurance Systems	150 points
Quality Results	150 points
Customer Satisfaction	300 points
	1,000 points

The Baldrige Award has received significant attention from American businesses since its inception. While only a small number of companies have actually applied for the prize (66 in 1988 and 40 in 1989), the number requesting applications from the NIST has grown dramatically (12,000 in 1988, 65,000 in 1989, and over 100,000 as of April, 1990). Companies are finding that the detailed evaluation criteria makes an excellent checklist for total quality improvement whether or not they intend to actually apply for the Award.

The following sections describe each of the seven categories and their applicability to shipbuilding. These discussions are followed by a case study of Motorola, which won the prize in 1988, and its winning approach to the seven categories.

Category 1.0 LEADERSHIP

This category examines senior executives' leadership in creating quality values, building the values into the way the company does business, and how the executives and the company project the quality values outside the company. Areas addressed include:

- Senior Executive Leadership: Personal involvement and leadership in quality related activities, such as goal setting, planning, review of quality plans, training, **competi-**

tive analysis, and customer relations; communication of this leadership inside and outside the company

- Quality Values: Policy, mission or guidelines that set the company's quality values and the internalization of those values in the company

- Management for Quality: Integration of quality values into day-to-day management at all levels of the organization; strategies for involving all levels of management in quality and their cooperation across divisions

- Public Responsibility: Extension of the company's quality values into the community, assuming its fair share responsibility for public health, safety, environmental protection, and ethical business practices.

To be successful from a quality perspective, top shipyard managers will have to both internalize high quality standards and lead management toward those standards. While this is not an easy task, some yards have stepped forward in some of the above areas, despite the costs. A good example is shipyards' stand on the double hull/double skin tanker issue. Of course a good portion of this stand is self-serving, but with proper communication, the yards' contribution to environmental protection can improve their image with the public and with some of their customers.

Leadership within shipyards is a delicate issue and one can always say it needs to be better. In this case as it relates to quality improvement, it is easier to find fault across the shipbuilding industry. The leadership intent may be there, but a cohesive and clearly communicated strategy is missing. How many senior shipyard executives can say they include quality as a key attribute of their management style?

Category 2.0 INFORMATION AND ANALYSIS

The information and analysis category examines the scope, validity, use, and management of data and information in support of the company's quality management system. Areas addressed include:

- Scope and Management of Quality Data and Information: The foundation of planning, management, and evaluation of quality

- Analysis of Quality Data and Information: The use of information in support of the company's quality leadership objectives.

At first glance, this category may seem impossible to most shipyards. However, shipyards do routinely collect and use much of the data needed to support this objective; they merely need to look at it in another way. Compared to most industrial manufacturing firms, shipyards have a much greater range of information available for analysis, particularly those yards involved in Government work. Shipyards must learn to sort out from this data usable information regarding the performance of processes and the quality measurement of interim products, and to augment it with more specific data to facilitate statistical process evaluation. Further, sorting this information to examine employee performance, education and training, quality teams, and recognition is probably a new perspective for shipyards.

Category 3.0 STRATEGIC QUALITY PLANNING

How does the company plan for retaining and achieving quality leadership and how is quality improvement planning integrated into overall business planning? Also examined are short term and longer term priorities to achieve a high quality position, including:

- Strategic Quality Planning Process: Short term (1 to 2 years) and longer term (3 to 5 years) planning for quality leadership and customer satisfaction, such as process capabilities, competitive and benchmark data, customer requirements and supplier information

- Quality Leadership Indicators in Planning: The company's approach to selecting quality related competitive comparisons and world class benchmarks

- Quality Priorities: Prioritization of objectives for quality leadership and the resources committed to reaching them.

This category alone should get every U.S. shipyard's attention, because it is essential to competing on a global basis. By understanding and planning for the quality needs of the world-wide marketplace, U.S. yards can begin to penetrate those markets. Setting quality improvement programs only to compete domestically will secure a share of a small market but will not begin to touch the much larger global marketplace.

Shipyards are beginning to use formal strategic planning processes and could factor quality planning into them. The Shipbuilders Council of America has been compiling information on the global shipbuilding industry which can be useful: however, establishment of specific quality-based goals, augmented by statistical processes, is necessary for strategic quality planning to be effective.

Category 4.0 HUMAN RESOURCE UTILIZATION

This category examines the effectiveness of work force development, including management. Areas of interest include:

- Human Resource Management: Human resource plans to support the company's quality objectives, both short term and longer term, and strategies for increasing the involvement, effectiveness, and productivity of all levels of personnel
- Employee Involvement: Total commitment to the company's quality objectives from top to bottom
- Quality Education and Training: Definition of education and training programs by employee category
- Employee Recognition and Performance Measurement: Strategies for encouraging contributions to the company's quality programs
- Employee Well-Being and Morale: Safeguards of the health and safety of employees and encouragement of a supportive work environment.

Due to the labor-intensive nature of shipbuilding, shipyards have long recognized the value of their work forces and typically have extensive human resource programs, but these programs can be improved in terms of total quality awareness. Some yards are expanding their use of employee involvement groups and shared decision making, education and training (often a necessity due to skilled labor shortages), and providing a greater stake in the future of the company to the work force through various economic incentive programs such as profit sharing. However, traditional personnel management methods and problems persist, including reliance on annual performance reviews and failure to deal effectively with traditionally high accident rates. Shipyards must continue to work on these and other "old school" issues if guality-based management backed by the entire work force is to succeed.

Category 5.0 QUALITY ASSURANCE OF PRODUCTS AND SERVICES

This category deals with systematic approaches toward quality control of goods and services based primarily on process design and control. Products and services are viewed broadly, since most companies have both product and service characteristics to consider. Areas to address include:

- Design and Introduction of Quality Products and Services: How new or improved products and services are developed, including test and evaluation processes and minimizing introduction time
- Process and Quality Control: Approaches used to ensure that production processes are controlled and that problems are identified and corrected
- Continuous Improvement of Processes, Products and Services: Principal approaches to identifying and implementing improvements, developing alternatives, evaluating new technology, and using competitive and benchmark data
- Quality Assessment: Assessment types and frequencies, who conducts them, and how they are interpreted
- Documentation: System that supports quality assurance, assessment, and improvement
- Quality Assurance, Quality Assessment and Quality Improvement of Support Services and Business Processes: Support services can include finance and accounting, software services, sales, marketing, information services, purchasing, personnel, legal services, maintenance, plant and facilities management, research and development, and other administrative services
- Quality Assurance, Quality Assessment and Quality Improvement of Suppliers: How the quality of materials, components, and services provided by other businesses is assured, assessed and improved.

Theoretically, shipyards should excel in this area since the QA function has been formally institutionalized due to Navy requirements. However, the QA functions present in most yards rely on mass inspection (often due to customer requirements), do not emphasize statisti-

cal techniques, and do not have the requisite organizational power to enforce quality-based change. In addition, the typical shipyard quality assurance function frequently misses the non-production side of the business, e.g., engineering and purchasing. While the Navy has forced quality improvements on the shipyards through the recent inclusion of "TQM" clauses in its contracts, it has simultaneously retarded the process through use of competitive bid contracting which in turn forces yards to use lower cost second-tier suppliers without emphasis on quality. As the budding commercial ship market strengthens, longer-term supplier relationships can be fostered.

Category 6.0 QUALITY RESULTS

The quality results category addresses quality levels and quality improvement based *on* customer requirements and business operations, both within the company and compared to competitors.

- Quality of Products and Services: Trends in quality improvement based on customer needs, including delivery and after-sales services, which together can predict customer satisfaction

- Comparison of Quality Results: Comparison with industry averages, industry leaders and world leaders

- Business Process, Operational and Support Service Quality Improvement: Measurement of use of manpower, materials, energy and capital, relating to lead times, yields, waste, inventory levels, rework, first-time success rates, environmental improvements, and other areas

- Supplier Quality Improvement: Trends in improvement of quality of goods and services provided by other companies.

In general, the shipbuilding industry has the systems in place to measure overall improvement. But it lacks the specific understanding of where it is with regard to specific processes, and, as noted above, needs to collect and analyze current performance data before embarking on a systematic program of improvement. Shipyards will need to take particular note of the customer focus of this category: true quality improvement will only be recognized when the needs of the customer are fulfilled. The yards probably have the information to internally quantify quality results but will face a greater challenge in bringing a customer and worldly spin to the information.

Category 7.0 CUSTOMER SATISFACTION

This category reviews the company's knowledge of the customer and customer satisfaction, including:

- Knowledge of customer Requirements and Expectations: Processes for determining current and future customer needs by market segments

- Customer Relationship Management: Understanding customer service requirements, providing easy access for customers to communicate with the company, solving customers' problems, and instilling a customer orientation among the employees

- Customer Service Standards: The company's standards governing the direct contact between employees and customers

- Commitment to Customers: Product and service guarantees and warranties and other commitments that the company makes to promote trust and confidence in its products and services

- Complaint Resolution for Quality Improvement: How the company handles complaints, formal or informal, and uses the information to improve quality and prevent further complaints

- Customer Satisfaction Determination: Objective and valid procedures to assess satisfaction by customer segments

- Customer Satisfaction Results: Customer satisfaction trends, including adverse indicators such as complaints, claims, refunds, recalls, returns, repeat services, replacements, downgrades, repairs, and warranty work

- Customer Satisfaction Comparison: Comparisons with industry averages, industry leaders, world leaders, and other competitors through surveys, awards, recognition, ratings, and market share analysis.

This examination category carries twice the weight of any other category and represents 30 percent of the total. Shipbuilders will argue that this is because the award is meant for consumer markets in which thousands of customers can be identified and their responses analyzed. However, the typical reaction of a customer of a U.S. shipyard is that "they don't understand or appreciate my needs." For this reason, this category

is probably the most relevant of the seven as the U.S. shipbuilding industry moves into the global market.

In this industry, the number of customers is small and their needs similar. This should make it easier to achieve high customer satisfaction, but the opposite has occurred over the last two decades. With a resurgence in the commercial market imminent, yards should begin to understand and appreciate how customers can be satisfied. They can begin by looking to other industries that have experienced similar challenges and draw parallels. They must talk to potential customers and find out what they want. Then the yards can devote the appropriate design and marketing resources to meet customers' needs. All aspects of the business need to be addressed, including marketing and sales, engineering and design, and finance resources.

CONCLUSIONS

Increasingly, leading companies are turning to the highly adaptable framework established for the Malcolm Baldrige National Quality Award as an effective alternative to the guru approaches. The Baldrige framework:

- Is management-led, data-based, and customer-driven
- Reflects the combined experience of quality experts in both the manufacturing and service sectors
- Is more comprehensive than but still compatible with the traditional guru approaches and affords companies the flexibility to tailor their initiatives to best meet their needs (i.e., use the best of the best)
- Provides companies with a mechanism to quantitatively evaluate the effectiveness of their quality initiatives
- Is continuously improved based on input from leading quality practitioners, academicians, and consultants.

United States shipbuilders can and should aspire to becoming one of these leading companies. Adopting a comprehensive program to address all aspects of the business from a quality improvement perspective can lead to a vastly improved market position as U.S. yards enter the lucrative global market of the 1990s. Whether any U.S. shipyard ever attains the award is not the issue; the real benefits come from trying. As shown in Figure 2, there are many potential uses of the Baldrige framework. There are also significant rewards.

Figure2:

Uses of Baldrige Framework

- Assessment
  - Award candidate assessment
  - Self-assessment
  - Supplier assessment
- Developing a total quality system
  - Quality improvement process
  - Checklist of issues
  - Interrelationships among issues
- Education and training
  - Major issues management must understand
  - Context for training specialists
- Communications
  - Within companies
  - Between companies and suppliers
  - Among companies seeking to share information
  - With current and potential customers

Case Study: Motorola

Motorola, Inc.
The company's quality goal: 'Zero defects in everything we do.'

Criteria	Major Quality Initiatives
Leadership	■ Senior management "crusade' addresses quality improvement as a company issue and, through speeches and full-page ads in major publications, as a national issue. ■ Top-level meetings to review quality programs, with results passed through the organization ■ CEO quality awards recognizing outstanding achievement within the company ■ Managers carry corporate objective of "total customer satisfaction" on printed card in their pockets ■ Corporate officials and managers wear pagers to make themselves available to customers and participate in a formal program of customer visits
Information and Analysis	■ Extensive network of customer surveys, complaint hotlines, field audits, and other customer feedback measures ■ Benchmarking programs used to analyze all aspects of competitors' product-service performance; 125 companies have been measured against Motorola standards
Strategic Quality Planning	■ Chief quality officer heads formal program of quality system reviews ■ Specific quality goals and standards established that drive key operational initiatives ■ Quality given priority on meeting agendas and in reviews, plans, compensation, and rewards ■ Quality planning a part of every employee's job
Human Resource Utilization	■ All employee levels involved in quality improvement ■ Participative Management Program (PMP) teams assess progress toward meeting goals, identify new initiatives, and work on specific problems ■ PMP bonuses average between 3 percent and 4.5 percent of total payroll ■ Motorola training center established ■ $44 million spent on worker education in 1987; about 40 percent of 1987 training (2.4 percent of payroll) was devoted to quality matters ranging from establishing quality principles to designing for manufacturability ■ Suppliers included in quality training and programs
Quality Assurance Systems	■ "Six Sigma Quality" statistical measurement process - employees record defects found in every function of the business ■ 'Total cycle time' reduction process-ongoing examination of the total system including design, manufacturing, marketing, and administration
Results	■ Achieved goal of improving product and service quality 10 fold between 1987 and 1989 ■ Service and product quality levels are approaching 99.9995 percent level ■ Cellular telephone operations achieved - 3O:l reduction in factory cycle time - 4:l reduction in defects per unit - Reduced part counts from 1,378 to 523 - 1O:l improvement in reliability
Customer Satisfaction	■ Recognized by customers as the leader in quality; company earned the highest number of supplier awards and certified supplier citations among 800 electronics companies ■ Over past two years, received nearly 50 quality awards and certified supplier awards, highest among 600 electronics companies ■ 1987 survey results indicate that among all semiconductor suppliers, Motorola provided the best coverage and customer support ■ Formal customer visit program for offices
Other	■ 1988 Malcolm Baldrige Award Winner ■ Twenty-three percent sates growth to $8.25 billion ■ Achieved largest market share of Japanese telephone paging market

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP1990 Ship ProductIon Symposium
Pfisrer Hotel. Milwaukee, Wisconsin, August21-24, 1990

Cost Effective Planning and Control

4A-1

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ABSTRACT

Situations have frequently been encountered where it is necessary to re-establish control of a shipbuilding contract when it has been lost. This has to be done quickly, and requires a combination of an effective planning and control system with a computer for data processing. Expediency dictated the use of readily available PCs and proprietary software.

The approach adopted was found to be robust and effective, and has been used as a basis for development of more formal planning and control systems. These are now in use as the means of planning and implementing ship production.

PLANNING AND CONTROL

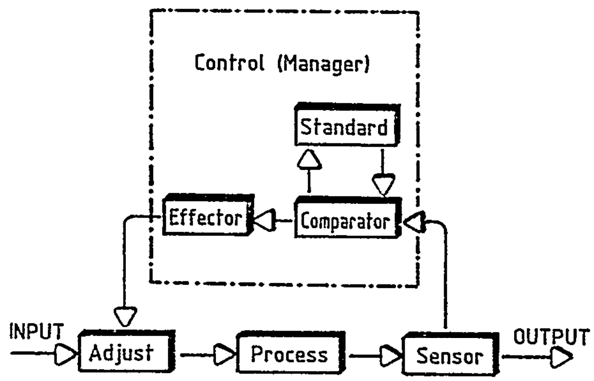
The importance of planning and control to ship construction (and refitting) is generally, if not universally, accepted. There is a wealth of literature on the subject and it may be questioned whether there is really more to be written. As a preface to the main theme of this paper, it is worth re-stating a few fundamentals that the authors regard as crucial to successful planning and control. (1)

The first is to remember that the objective is to gain and keep control of the project. That is, the plan must be produced early enough to be acted upon and the control system must give enough information to permit corrective action when necessary. This system must have all the elements of a feedback loop (Figure 1). In practice, one or more elements is often missing.

Secondly, as an extension of the above, the control system must be able to operate in a timely manner. This gives rise to two requirements. The feedback of information must be fast, and it must be based on the completion of work packages at their associated work stations. In a shipbuilding

Figure 1

COMPLETE FEEDBACK LOOP



The Standard represents planning.

The Sensor measures output.

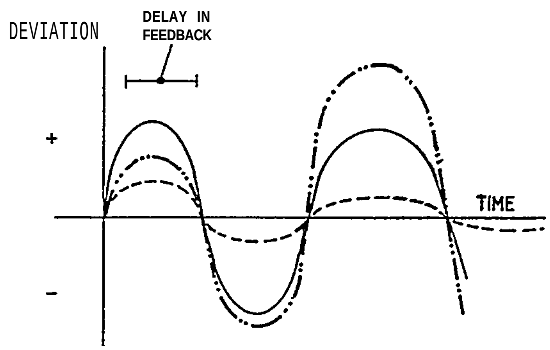
The rest of the system provides control.

context "fast" implies a timescale of weeks or days. Figure 2 indicates that feedback which is not timely will be of no value for the purpose of control, and may make a bad situation worse.

The measure of progress should be that a work package is complete or not. This will result in marginally understated progress, but will avoid often over-optimistic reports on percentage completion.

Thirdly, the authors consider that a hierarchical planning system is essential (2). This typically gives three levels of planning, which correspond to different time horizons and levels of detail. Typically these will be:

Figure 2



System fluctuates without feedback.

System with feedback reaches stability.

System with delayed feedback has increasing instability.

Strategic, covering all projects and with a time horizon of years.

Tactical, covering a project or development, with a time horizon of months.

Detail, covering work stations, with a time horizon of weeks.

These are deliberately loose definitions; in practice the hierarchy must be tailored to a particular situation.

Finally, the system must be correlated with accounting, so that management of the work and of the costs are synonymous. The accounting function is required to make precise allocation of costs after completion of a project. Management can accept imprecision, but requires a continuous flow of information during a project. These objectives need not be in conflict (but often are).

PROBLEMS

It has been the authors' experience that, although the theory of planning and control is well understood, in practice actual control is often not achieved. The lack of control does not appear to be necessarily associated with the lack of, or the existence of, a planning system. Although shipyards which operate with minimum strategic level planning usually have no control, systems with large volumes of data can co-exist with an almost total lack of control.

Where the system is minimal, work is performed as it becomes available. Where the system is sophisticated, much of the effort is concentrated on amending the plan to reflect out-of-control production.

At the risk of being repetitious, the objective is to determine and then achieve set goals; to be in control of operations.

The nature of control has been usefully defined by Ashby's law of requisite variety (3). This puts forward the concept of the variety of a given system. Simply, the variety is a function of the number of people, number of interim products, and so on. In order to manage a system, the variety available to the control system must equal the variety inherent in the system. To the extent that this matching of variety is not achieved, the system (ie, shipyard) will not be under control. It is easy to see why a limited planning system does not match production variety. It is less obvious how a more sophisticated system can fail.

Figure 3 gives a simple explanation. Since a direct match of variety is not achievable - it would require a "manager" to stand over each worker - variety must be dealt with in some other way. Two possibilities exist:

amplify the variety of the control system;

attenuate the variety of the system to be controlled.

Although this is a very simple model, it is powerful and effectively defines any management situation.

Figure 3 shows two possible systems. In the first, information from the system is attenuated, so that only that which is essential is passed to management. The management information is then amplified, to give enough variety to match production. This is what should happen, and in practical terms is represented by:

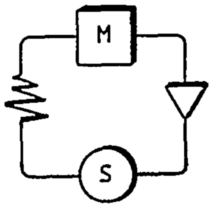
hierarchical planning;

hierarchical management:

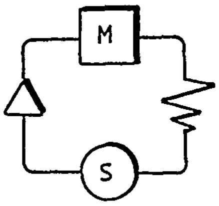
standardisation (of products and methods);

short duration work packages to minimise WIP.

Figure 3



Information from Manager (M) is amplified (∇) to match variety of system (S). Information from system is attenuated to allow manager to cope.



Attenuator and amplifier are in wrong parts of the feedback loop.

In the second system, the amplifier and attenuator are reversed. Thus, the information from the system is amplified. Typically, this is represented by a computer print-out with thousands of line items and different ways of sorting this information which is presented to senior management. Similarly, the management information is attenuated, because it cannot keep pace with the changing situation in production. Planning (so-called) is reduced to an attempt to maintain a record of what is actually happening in out-of-control production.

Typical symptoms are:

- over centralisation;
- excess work in progress.

SOLUTIONS

In the authors' and colleagues' experience situations are often encountered where it is necessary quickly to establish the status of a shipbuilding or shiprepair contract. To do so it is essential to be able to use existing data relating to the contract. This is usually in plentiful supply but seldom in a coherent form. To be able to respond to such situations methods were developed to use readily available software (a computer is essential to carry out the necessary analysis quickly). Although the methods developed are essentially simple, because they must be set up rapidly, they have proved surprisingly robust and accurate for their intended purpose.

In 1989 a company was set up within the authors' Group to build luxury yachts. It was seen to be necessary to apply systematic planning and control for labour and materials. The opportunity was taken to apply the previous experience in the application of product orientated production systems to shipbuilding activities. The system which has been developed as a result provides facilities for planning and progress monitoring, at various levels of detail from contract to work package, and for materials control from specification through procurement and issue to work packages. For planning and progress monitoring the system includes:

- budget and actual labour hours;
- planned start and finish dates;
- actual start and finish dates;
- forecast to completion:
- forecast of resource loading.

For materials control, the system includes:

- material identification by ship system;
- purchase requisition and orders;
- material list for work packages;
- material receipt, storage and issue status;
- budget and actual expenditure.

The software was developed using a proprietary database product for an IBM compatible personal computer. It is menu driven, and uses customised input screens to simplify the task of the user. Since its introduction, the system has been extended to additional outfit activities in the original shipyard and, more recently, has been introduced to another of the shipyards which undertakes more large scale contracts.

Success in planning and control of shipbuilding activities is dependent at least as much on the setting up of, for example, work packages within a coherent planning framework, as it is on the control software. To date the approach outlined below shows considerable promise of providing a flexible and cost effective way of managing ship production.

THE SYSTEM

System Requirements

Key factors in the system design were:

It should support the principles of Product Work Breakdown Structure (PWBS) based production. It should address the areas of manhour planning, progress monitoring and materials control, which are felt by APA to be key elements of control.

It should be simple to implement, so that immediate benefits may be achieved.

The system should be intrinsically "simple" in concept, since the scope for introducing complexity was endless a conscious effort was made to "keep it simple".

It should be simple to use, so that staff training is minimal.

It should be capable of running on readily available hardware (IBM PC or compatible), allowing its introduction in a small way with the possibility of growth via a Network of PCs if required.

It should be capable of allowing ad-hoc enquiries and reports to allow maximum use of the information contained within the system.

Material Identification and Procurement

Early in the life of the contract key items of material and equipment may be identified (by system). Thus begins the development of the Materials List by System (MIS). As the contract design evolves the MLS is refined and updated with additional materials and/or revised quantities and due dates.

Items which have been added to the list or have been amended are identified by the computer and a purchase approval list, or modification list, is produced as appropriate for action by the materials control function.

The materials controller assigns purchase order numbers for new materials/equipment or issues revisions for amendments to orders which have already been placed. The computer system produces draft purchase order documents which may be further word processed if required before printing and issue to the supplier. A Goods Received Note (GRN) is also produced for subsequent use by stores to record receipt of the materials.

The system will produce reports identifying specific groups of material or analyses, eg:

Items requiring QC inspection on receipt.

Expected delivery schedule.

Committed costs by contract/ system.

Expected cash outflow by month.

Materials control.

For production purposes the contract/ system breakdown of the initial contract estimate is developed into a product orientated breakdown and planning units, stages and work packages are identified.

The items within the MLS are reclassified to identify the work package to which materials belong. This allows the production of work package "kit lists".

In addition, the status of material by work package, ie, ordered, received, where stored, may be enquired upon on line.

Labour Manhours

Tactical Planning. The initial estimate is ship system orientated, and may be recorded within the computer system. The estimate should be based on a continuation of historic work station productivity and realistic plans for improvement.

Early in the life cycle of the contract a series of planning units is identified for the contract. The number of planning units is to some extent dependent upon the type and size of vessel planned; however, typically, the contract would be broken down into some 150-300 planning units.

The ship system manhour budget is re-allocated over these planning units by work type (skill). Thus typically each planning unit would have a manhour budget of the order of 5-6,000 manhours. Each planning unit is also allocated a planned start and planned finish date. This data is input to the computer system and used to forecast initial manpower loadings, to allow early identification of possible overloads, etc.

Any necessary action is taken to achieve a balanced and achievable work load, eg, adjustment of planned start/finish dates, planned increase of available manhours, etc, and so a realistic plan is determined at planning unit level.

Detailed Planning. As the contract progresses work packages are identified within each planning unit and are assigned a portion of the planning unit manhour budget. Work package size is typically enough work for a small team for a period of 1-2 weeks, ie, approximately 150-300 manhours. The work package should be a readily identifiable task whose completeness or otherwise can be clearly determined.

These details are input to the computer system which monitors the allocation of manhours to work packages to ensure that global manhour budgets by planning unit are not exceeded.

Each work package as it is identified is assigned a planned start and finish date. It is possible if required to identify all work packages at the beginning of the contract, however a more normal approach is to identify work packages some 4-6 weeks before work is due to begin and to ensure materials are/will be available when required.

The work package budgets and planned start/finish dates are used to produce more detailed forecasts of labour loading by work type (skill) with a (typical) six week horizon. This allows the production of detailed production schedules with (say) a four week time horizon.

Since the overall labour loading has been examined during the higher level planning process at planning unit level the labour loading at work package level should in theory be broadly acceptable. However inevitably peaks and troughs are encountered but since a 4-6 week advance warning of unacceptable forecast labour loading is available early (corrective) action may be taken (eg, subcontract, reschedule, planned overtime working, etc). In this way any difficulties are contained and do not detract from the overall planning unit planned start and finish dates which are ultimately tied to timely contract completion.

Progress Recording and Performance Monitoring. As work progresses on the work packages actual manhours used are collected for each employee by work package and are recorded within the computer system. Actual progress by work package is also recorded (ideally on a finished/not finished basis rather than a percent complete basis since this eliminates any subjective judgements on the part of the foreman or who-ever) and is entered into the computer system.

The computer system is then used to report upon contract progress and performance against budget at various levels of detail:

Contract summary reports for senior management.

Planning unit summaries for production management.

Work package detail for shop floor supervision.

At all levels of detail the reports concentrate on two key points:

Are we on schedule?

Are we on budget?

by highlighting both overruns against budget and deviations from planned progress. Forecast manhours to complete based upon current actual performance are also included, as a basis for corrective action.

CONCLUSIONS

The experience gained, in both developing systems to establish control and in their application, has convinced the authors of a number of important points.

It is better to have planning that is effective at a coarse level of detail than ineffective in fine detail.

It is better to be approximately correct early than precisely correct too late.

It is essential that the system allows corrective action to be taken.

Management efforts should be concentrated on establishing planning units which allow these criteria to be met, with data processing available to speed the manipulation of information.

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Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24, 1990

Solving SARA Compliance with Computerized Hazardous Materials Tracking

4B-1

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ABSTRACT

The advent of the Superfund Amendment and Reauthorization Act **(SARA)** Title **III**, or the Emergency Planning and Citizen Right-to-Know Act (EPCRA) has forced facilities to keep track of hazardous materials as never before. EPCRA contains five major reporting requirements including planning notification, emergency release notification, Material Safety Data Sheet (MSDS) submission, chemical inventory reporting and toxic chemical release reporting. The complexity and vastness of the above requirements all but requires a computerized system for hazardous material management.

Peterson Builders, Inc. developed a computerized hazardous materials management system capable of meeting the requirements of EPCRA. AFter one year of operation, the system has proven successful. This paper discusses Peterson Builders experience in implementing the system, system design, and future considerations for the system.

NOMENCLATURE

DBMS. Data Base Management System.

EHS. Extremely Hazardous Substance.

EPCRA. The Emergency Planning and Community Right-To-Know Act, or SARA Title III.

LAN. Local Area Network.

LEPC. Local Emergency Response Committee.

MSDS. Material Safety Data Sheet.

OSHA. The Occupational Safety and Health Act, or The Occupational Health and Safety Agency.

pc. Personal Computer. P.O. Purchase order.

RQ. Reportable Quantity.

SARA. The Superfund Amendment and Reauthorization Act.

SERC. State Emergency Response Commission.

TPQ. Threshold Planning Quantity.

INTRODUCTION

SARA Title III.

In October of 1986, Congress passed the Superfund Amendments and Reauthorization Act, otherwise known as SARA. Like its predecessor, the Comprehensive Environmental Restoration and Contamination Liability Act (CERCLA), SARA dealt with the restoration of sites contaminated by toxic and hazardous wastes. Unlike its predecessor, SARA contained a stand alone act under Title III, otherwise known as the Emergency Planning and Community Right-To-Know Act, or EPCRA.

EPCRA was developed in response to chemical catastrophes such as the Methyl IsocyaTate release in Bhopal, India . Thousands of people were killed or left with permanent disabilities. Several toxic chemical releases in the United States occurred after Bhopal, including a Methyl Isocyanate release in Institute, West Virginia shattering the "it could not happen in the U.S." myth. No deaths occurred in Institute, but six workers and twenty five community members

were hospitalized. Congress, driven by a sensitized and outraged public, took action.

Any facility that possesses certain chemicals over Threshold Planning Quantities is subject to regulation under EPCRA. The chemicals covered by EPCRA are divided into three categories; Extremely Hazardous Substances, Toxic Chemicals, and CERCLA Hazardous Substances and Occupational Safety and Health Act (OSHA) Hazardous Chemicals. There are discrete lists for Extremely Hazardous Substances and for Toxic Chemicals. The third category, a combination of chemicals regulated under CERCLA and OSHA does not have a discrete, finite list. OSHA regulations are performance based, setting criteria under which a chemical is regulated. An estimate of the number of chemicals regulated by OSHA is over 50,000 .

There are five key sections of EPCRA that contain reporting and notification requirements with which facilities must comply .

1. Section 302 of EPCRA deals with Emergency Planning Notification and is based on the Extremely Hazardous Substances (EHS) list. All facilities that produce, use, or store an EHS above the Threshold Planning Quantity (TPQ) for that chemical must notify the State Emergency Response Commission (SERC) that EHS's are located at the facility.

2. Section 304 requires facilities that produce, use, or store OSHA Hazardous Chemicals to report accidental releases of Extremely Hazardous Substances above a Reportable Quantity (RQ) to the Local Emergency Planning Committee (LEPC), the SERC and to the EPA Regional Administrator.

3. Section 311 requires facilities subject to the OSHA Hazard Communication Standard (HCS or "Hazcom") to submit Material Safety Data Sheets (MSDS) to the local Fire Department, the LEPC and the SERC. A list of chemicals at the facility along with their hazardous properties can be submitted instead of MSDS's. New or updated Material Safety Data Sheets must be submitted with 90 days.

4. Section 312 requires that a facility annually report all Extremely Hazardous Substances, CERCLA Hazardous Substances, and OSHA Hazardous Chemicals present at the facility in quantities exceeding the reporting threshold. At present, the threshold for OSHA Hazardous Chemicals is 10,000 pounds. Extremely Hazardous Substances have a threshold of 500 pounds or an individual RQ, whichever is lower.

5. Section 313 requires that a facility report emissions of Toxic Chemicals processed, manufactured or otherwise used above a set threshold. The threshold differs depending on how a facility handles a chemical: 25,000 pounds for chemicals manufactured or processed, and 10,000 pounds for chemicals that are otherwise used. This requirement applies only to facilities in the Standard Industrial Classification codes 20 to 39 and that employ 10 or more employees.

<u>Developing the Hazardous Materials Tracking System</u>

The complexity and amount of data involved with EPCRA compliance dictated the need for a computerized data base management system. The shipyard has over 1500 MSDS's, most containing multiple chemical components. Each of these chemicals must be evaluated to determine if they must be included in a SARA 312 or 313 report come reporting time. Shipbuilding also dictates the need for tracking hazardous materials. The Local Emergency Planning

Committee (LEPC) requires that the location of hazardous materials be known for emergency planning purposes. Since ships can not be easily moved, hazardous materials must be moved to construction sites. As the building of a ship at a given location progresses, the types and amounts of hazardous materials at the location changes. To handle the ever changing conditions, it was decided to track the containers holding the materials regulated under EPCRA.

The first decision that was confronted was that of creating our own tracking system or purchasing a software package with tracking capabilities. After an extensive review of the packages available at the time, the decision was made to build our own system. Only a few software package? offered tracking capability[4]. Available packages provided chemical tracking. Most hazardous materials used are mixtures of chemicals however. To complete a transaction in the available software packages, an entry would have to be made for each chemical in the mixture. This would have become very tedious for hazardous materials composed of many chemicals. A tracking system that was based on container transactions (receipt, movement and consumption) was needed.

The shipyard had approximately 40 Personal Computers (PCs) linked together in a Local Area Network (LAN). The decision was made to utilize the existing Database Management System (DBMS) on the LAN for the tracking system. Most manufacturing units that handle hazardous materials had access to a PC linked to the LAN. Most manufacturing departments also had personnel trained to use the DBMS on the LAN. The system was conceived with the requirement that each manufacturing department be responsible for data entry for its hazardous material transactions. It was hoped that requiring each department handling hazardous materials to perform their own data entry would distribute the workload, help develop awareness of Hazardous Material usage and keep data accuracy high. Additional PCs were purchased and personnel trained for those departments lacking these commodities.

DATABASE STRUCTURE

Normalization.

The design of the database began with the decision to follow the Third Order Normalized structure [3]. Normalization is a process of grouping data together in a form that is more amendable to change and that minimizes the impact of change to the system. The need to develop a system that can handle change was considered vital since environmental regulations change constantly. System development began in October of 1988, with a desired on-line date of January 2, 1989. This allowed only two months for system development, so the design of the system was made to allow for easy modification. Third Order Normalized structure allowed for easier and less disruptive fixes later on.

Groping of Data.

The Hazardous Materials Tracking System is comprised of three major data groups.

1. Container Information: Includes container type and size, contents, location, amount used (removed from container) and dates of receipt, movement, and use. All data relating to the use of hazardous materials is kept on a container basis.

2. MSDS Information: Includes chemical components (with Chemical Abstract System (CAS) number, lower and upper percentage of composition), product name(s), manufacturer (name, address, and phone number(s)), and physical, health, safety and emergency response data.

3. <u>Regulatory Information:</u> Includes Threshold Planning Quantities (TPQ) and Reportable Quantities (RQ).

A seven digit product code is assigned to each different hazardous material. Different product codes are assigned to the same hazardous material obtained from different manufacturers. Product codes are assigned sequentially, without any attempt to assign significance to any individual digit or groups of digits. The only exception to this rule is that the first digit is assigned as 7. The product codes were designed to match the format of a number assigned materials by the Material Control Department to those materials purchased under contract. Many noncontract materials were found to be hazardous materials. It was hoped that the product codes assigned by the Environmental Affairs Department could be used by the Material control Department.

A seven digit number is also assigned to each container tracked on the system. Rolls of one inch by two inch labels are purchased with preprinted numbers running in consecutive order. The first two digits of the number represent the year that the labels were purchased. A new sequence of numbers is started with the first label purchase of a new calendar year to avoid ever increasing container numbers.

Information about containers is stored in two separate files. One file, called CONTAINER stores information about the present state of containers. This file can be queried to determine the number of containers present for a certain product and where those containers are located. The CONTAINER HISTORY file stores information about container transactions. Some of the possible transactions that are recorded are: receipt (arrival of material at the shipyard); movement (physical change in location); transfer (between departments); and consumption. The date and time of each transaction is recorded.

MSDS data is stored in three files; PRODUCT, COMPONENT, and SYNONYM. The PRODUCT file contains the majority of the data pertaining to each hazardous material, including the hazardous material's name, manufacturer, physical attributes, and health and safety data. All data in the PRODUCT file was standardized as much as possible - the possible responses for each field were restricted to a few choices or the choices were predetermined. Standardizing MSDS data requires personnel with a good working knowledge of MSDS information. Entry time is greater than for copying information verbatim but data storage space is saved. The standardized data is not meant to take the place of MSDS information, but to provide data for report calculations and quick reference data in an emergency.

The COMPONENT file contains the chemical information from MSDS's: CAS number (or a component number when CAS number is missing); and the minimum and maximum percentage of the chemical in the hazardous material. When the percentage of a chemical is not given, zero (0) percent is assumed for the minimum and 100 percent is assumed for the maximum. Chemical names are stored in the SYNONYM file.

Regulatory information pertaining to individual chemicals is stored in the CAS file. All the EPCRA TPQ's and RQ's are assigned on a chemical basis, as are most environmental regulatory limits. Some regulations are based on the attributes of the hazardous material and not its individual components. An example is hazardous waste characteristics: ignitability, corrosivity, and reactivity. Data pertaining to the hazardous material as a whole is stored in the PRODUCT file.

Data Output.

Data can be obtained from the tracking system three different ways: Queries, Reports, and Batch processing programs. Most commercially available Data Base Management Systems include the capability to perform queries, generate reports or run batch processing programs. The DBMS installed on the shipyard's LAN is a hierarchicai- database, not fully relational. The lack of full rationality limits the guery capability and causes the need to use the report generator or batch processing programs to a greater extent.

The simplest way of obtaining data is by guerying, or conducting a 'conditional search' of the database. In a guery, the user simply enters the program and calls up one of the data screens. The user then enters the conditions of the search they want to perform by filling a data field or fields. The use of multiple data fields in a guery are used to narrow a search. The appropriate key sequence is then entered to start a search. The output of a search can appear either on the computer screen, or be printed on a connected printer.

More complicated searches can be performed by using the report generator. The report generator also allows for greater flexibility in designing how the output will appear. The report generator is needed when several different data files are involved in a search. When the search criteria becomes too complex for a report generator to handle, batch processing programs are needed. A batch processing program is an actual computer program, written in the computer language supplied with the DBMS. Some DBMS's allow for the use other computer languages.

DATA FLOW

Hazardous materials enter the facility either under a shipbuilding contract, a shop order, or from purchase from a local merchant, such as a hardware store. Contractual and shop order materials are purchased through the issuance of a purchase order (P-0.). Purchase orders are generated on a mainframe computer system which in turn, creates a notice to the Receiving Department to expect a shipment. When material arrives at the shipyard, the Receiving Department generates an inspection report utilizing P.0. information and compares the material received against the information on the P.0.. If the material matches the P.0. description and is not damaged, the material is accepted and a receipt of material received report is generated.

When purchase orders are issued for materials that might be hazardous materials, a statement about Material Safety Data Sheets is included on the P.0.. The statement requests that the vendor either supply MSDS's (one prior to shipment and one with the shipment) or a statement that the material does not require a MSDS. All copies of MSDS's sent by vendors prior to a material's shipment are routed to the Environmental Affairs Department. Each MSDS received by the Environmental Affairs Department is checked to see if it is for a new hazardous material, an updated MSDS for a currently used hazardous material, or a duplicate of an MSDS that is already on file (not an update). If the MSDS is for a new hazardous material, a product code is assigned to the hazardous material . All pertinent data on the MSDS is transcribed into the PRODUCT and COMPONENT files of the Hazardous Material Tracking System.

When material arrives at the shipyard, warehouse personnel route all materials that are hazardous to a special hazardous materials warehouse. At this warehouse, the containers of hazardous material are labeled with the one inch by two inch tracking label. The label is affixed as close to the container label as possible. The warehousemen then enter the receipt of the material into the tracking system. Product codes are assigned to the received materials by

examining a computer list of possible product codes. The list is sorted by product name, manufacturer, and product code to assist the proper product code assignment. If a problem arises with assigning a product code, the warehouseman calls the Environmental Affairs Department. At present, only hazardous materials that are packaged in containers one gallon in size or larger are tracked.

When a hazardous material is requested by a shop, the warehousemen deliver the materials and enter information about the movement into the tracking system; the date and time of the delivery, receiving location and department, the employee number of the person who requested the material, and the container numbers of the moved material. Once a hazardous material is out of the warehouse, it is the responsibility of the department that received the material to record further movements, transfers or when the container is empty. All containers are considered as being either full or empty, although the tracking system has the capability of recording fractional use. Other 'transactions' that the tracking system can recognize are: transfer from a container into a tank: refill of a container (complete or fractional); the appearance of a container from an unknown origin; and off-site transfer of a container (such as shipment for disposal).

When a container is recorded as empty, the department in control of the material affixes a round fluorescent pink label to the container, close to the tracking label. Facility personnel have been instructed to hold any tracked container being discarded without the pink circle and to inform the Environmental Affairs Department. This prevents any tracked container from being discarded prior to being recorded in the tracking system as empty.

DISCUSSION

The development of the hazardous material tracking system was performed in only a two month time frame. With such a short period of time allotted for development, problems were expected to occur. Surprisingly, few major problems occurred related to the database design. Database design problems consisted mostly of such items as inefficient screen layouts, or failure to make certain data fields mandatory when information was entered.

One significant problem involved the CONTAINER file. The original plan for this file was to remove and archive data on empty containers on a yearly basis. Unfortunately, the number of containers tracked was larger than expected and this file became unwieldy. Queries of the CONTAINER file started taking too much time to be useful should an emergency arise. The solution, presently being implemented, was to split this file in two. One file will hold data on non-empty containers. The other file will hold data on empty containers.

Certain problems arose with Material Safety Data Sheets. An assumption was made that there would be a one-to-one correspondence between products and MSDS's. This was true for the most part, but exceptions were found, especially with coatings. There were several instances where several coatings had one MSDS, such as the F150 series of paints. Some coatings also had more than one MSDS that could apply. For instance, there is a MSDS for the F150 through F159 series paints and a MSDS for an F153 paint.

Multiple component systems presented problems that have yet to be resolved. Some multiple component systems have separate MSDS's for each component, some only have one MSDS for the components as a whole. Decision criteria need to be devised to decide how to track multiple component systems. Should each component be tracked separately, or should the system be tracked as a kit?

Data entry has also presented some problems. Delays in data

entry have caused the container inventory to be inaccurate. Some container history records show a container being emptied before it was ever moved out of the receiving warehouse. Worse yet, some containers were transferred into one of the yards and were consumed before they were ever entered as being received. When the manufacturing department vent to enter the container as being consumed, they could not find a record for the container.

A monthly inventory reconciliation program will be initiated soon to overcome tracking errors. At present, there is not a formal inventory reconciliation procedure in place at the shipyard. One partial check was made in June of 1989, which showed a error rate of approximately eight percent. Reports will be sent to each department that has tracking responsibilities each month. Each department will compare their physical inventory against the tracking system inventory and report any deviations.

Some products were received prior to a MSDS being received and a product code being assigned. The warehousemen could not find a product code to assign the received containers. This problem was solved by assigning a product code with minimal information entered into the system. A phone call would be made to the manufacturer or vendor, requesting that an MSDS be faxed immediately.

Personnel turn over presented some nagging problems with the tracking system. Some key people were lost and the data entry burden had to be picked up by others while a new person was trained. In one instance, a person was lost and the department never reassigned a person to perform data entry duties. An inventory report spotted an unusually large inventory for that department. Investigation showed that the consumption of containers had not been entered into the tracking system.

Currently containers of hazardous materials are only recognized as being either empty of full. Partial consumption, or draw down of containers is not recorded although the tracking system has this capability. There are plans to add a tool room for the distribution of paint and paint solvents. A tool room is necessary to gain the control needed to track partial consumption. The driving force behind the creation of the paint tool room are requirements from the state environmental regulatory agency to record Volatile Organic Compounds and air toxics emissions more precisely than in the past.

RECOMMENDATIONS

Before implementing a tracking system, be sure to get the input of all departments that have to or may use the system. This will make them feel a part of the process and gain support for the system. There is also a wealth of knowledge that can be tapped. Many people at the shipyard offered excellent suggestions on how to improve the system by adding features they could use and making the system easier to use.

Several departments fought the development of the tracking system at first. Expect to have to perform some lobbying for the system. Point out the benefits of a tracking system. Several manual inventory systems were replaced, and manufacturing departments have the luxury of knowing their inventories at a few keystrokes. The purchasing department has found the system to be of benefit by checking inventory prior to ordering consumables that may have short shelf life.

If at all possible, purchase a fourth generation, fully relational DBMS for the tracking system. These advanced DBMS's should allow for easier development and the ability to obtain most of the information you need by query instead of report generators or batch processing programs.

ACKNOWLEDGEMENTS

The authors thank the following people for their contribution to the development of the Hazardous Materials Tracking System.

Mr. Gary Higgins

Mr. Gerald Huber

Mr. Steve Pope

Mr. Tim Ullman

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24,1990

Hazardous Waste Minimization Program At Philadelphia Naval Shipyard

4B-2

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ABSTRACT

The Chief of Naval Operations (CNO) set forth the goal to reduce hazardous waste generation by 50% by 1992. This has provided Naval installations such as Philadelphia Naval Shipyard (PNSY) with an increasingly defined role as active participants in the nationwide effort to reduce or eliminate the generation of hazardous waste. PNSY Industrial Engineering Division has developed a comprehensive plan targeted at managing and reducing hazardous waste generation in the shipyard.

The first goal. of the plan was to analyze and identify all the potential hazardous waste streams generated within the shipyard. A directory of all the shipyard waste streams was compiled indicating the type of wastes generated and the processes from which they originated. Upon completion of this identification, a Pareto Analysis was performed to rank the waste streams in consideration of quantity generated, cost of disposal and toxicity. The high ranking waste streams were targeted for immediate remedial action. This ensured success in meeting and exceeding the CNO goal and achieving maximum payback on engineering manhours dedicated to the program. These waste streams and the industrial processes which generated them were carefully analyzed. The feasibility of eliminating/recycling them through a process change or on-site treatment to effectively reduce their volume was studied. The Industrial Engineering Division has since initiated a variety of projects including treatment/recycling/elimination of hazardous waste in addition to critical process changes which reduce volume generation.

Success of this program is continuously pursued as part of Total Quality Management and will allow Philadelphia Naval Shipyard to achieve the CNO goal, ensure compliance to federal, state and local regulations and produce a cost savings/avoidance for the shipyard in excess of 1 million dollars within the first two years of implementation.

BACKGROUND

The Philadelphia Naval Shipyard (PNSY) along with many private and public sector organizations utilizing hazardous materials have become increasingly aware of the importance of hazardous waste minimization. This is mainly due to three factors, total adverse impact of hazardous waste to the environment, rapidly increasing hazardous waste disposal costs, and growing legal and financial liabilities for noncompliance to regulations such as the Resource Conservation and Recovery Act (RCRA).

Due to the nature and extent of their operations, large Naval installations such as PNSY, have the capability of generating considerable amounts of hazardous waste within a short period of time. Along with this capability comes the responsibility and liability for legal, effective and economical management of this waste. OPNAVNOTE 5090 of May 1988 issued by the Chief of Naval Operations (CNO) set forth the goal to reduce hazardous waste generation by 50% through the five calendar year period 1988 to 1992 (base year being 1987). This policy statement emphasized the Navy's commitment to hazardous waste reduction and provided all Naval installations with a clearly defined goal and a measure on which to base the success of their minimization efforts.

Philadelphia Naval Shipyard under

guidance from Naval Sea Systems Command (NAVSEA), initiated a full scale, comprehensive program to manage hazardous material and minimize generation of hazardous waste. This program addresses management controls, hazardous material controls, waste minimization initiatives and proper handling and disposal of hazardous waste. As part of this program, the Industrial Engineering Division has been specifically assigned to analyze production processes in an effort to minimize hazardous waste. Two main objectives have since been set by PNSY Industrial Engineering. Primarily, achieve the CNO goal of 50% reduction in hazardous waste and secondarily, achieve a hazardous waste disposal cost savings of at least $1,000,000 within the first two years of implementation.

MINIMIZATION STRATEGY

To effectively implement a hazardous waste minimization program, a comprehensive plan must first be developed. With long term minimization methods such as management controls for hazardous material acquisition, handling and disposal already implemented, Industrial Engineering focused directly on production processes generating hazardous waste. A waste stream directory was compiled to identify all processes generating waste, the type of waste generated, characteristics of the waste and the EPA identification number.

Considering the numerous sources of hazardous waste and the limited time frame available to achieve 50% minimization, Industrial Engineering compiled a "Top Ten" hazardous wastes list. The main criteria for choosing candidates for this list was highest volume generated and toxicity. This list was then arranged in a Pareto format, figure (l), to indicate a hierarchy of the top shipyard hazardous waste streams.

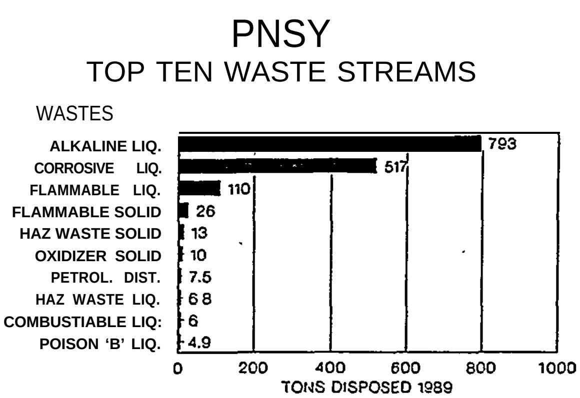

figure 1.

Analysis indicated that an 80% reduction of the first three waste streams, specifically alkaline liquid, corrosive liquid and flammable liquid, would result in achievement of both initial objectives. All major processes contributing to these waste streams were subsequently identified. These included electrical motor cleaning, metal pipe processing and a variety of cleaning and painting operations utilizing solvents.

Having the problem sufficiently defined and narrowed, the next step in the plan was to identify the most effective methods of minimization. Several industry proven alternatives were considered. Given the desired cost savings objective, contractor treatment or disposal was not considered. Additionally, considering time limitations, process changes requiring extensive testing and approval were given a lower priority. The remaining potential minimization techniques were reduced to four major categories:

1. Elimination

Eliminating and/or substituting hazardous chemicals in a process greatly reduces the toxicity of a waste stream generated by that process. Processes contributing to the three top waste streams were examined to determine if a less hazardous chemical or a process change could be used to reduce or eliminate the toxicity of the waste stream without affecting the quality of the end product.

2. Reutilization

During a production process a hazardous waste stream may often be generated that need not be referred to as "waste". Partially contaminated chemicals such as cleaning solutions or solvents may be used in a less stringent application or in the original application if they can be decontaminated in a cost effective manner (such as filtering).

3. Reclamation/Recovery

Solvents such as mineral spirits and Freon possess unique properties which allow them to be effectively distilled out of a waste stream to very high purity levels. Additionally, recent technology has provided the capability to capture and liquefy working gaseous refrigerants (CFC's). This process will provide an alternative to venting the gases into the atmosphere upon overhaul of equipment containing them.

4. Minimization by Volume Reduction

Minimization by volume reduction can provide significant hazardous waste minimization with an outstanding payback and return on investment. This, however, is often achieved with high initial investment costs (over $20,000) and the need to acquire local permits. Volume reduction often involves treatment to render a dilute waste stream non hazardous. This treatment will usually concentrate hazardous constituents to a volume of 103 or less of the original waste stream.

External Technology Sources

To support the overall hazardous waste minimization effort, the Navy has dedicated certain functions of activities such as Naval Civil Engineering Laboratory (NCEL) and Naval Energy Environmental Support Activity (NEESA) to the development and implementation of hazardous waste minimization technologies.

There are several economic and applications advantages that this technical support provides to U.S. Naval installations. The majority of the research and development-required for these minimization projects is completed by NCEL or NEESA, thus saving local engineering costs. Additionally, these projects are specifically engineered for U.S. Navy related industrial operations. These minimization technologies include Hard Chrome Plating Retrofit, Boiler Hydroblast Solution Recycling and Recycleable Plastic Blast Media.

Implementation of minimization projects developed by activities such as NCEL and NEESA was given a high priority by the Industrial Engineering Division.

MINIMIZATION PROJECTS

Since the implementation of the Hazardous Waste Minimization Program, numerous projects have been initiated utilizing the guidelines outlined above. The following implemented or nearly implemented projects are presented.

Electrical Motor Component Cleaning

This operation generates approximately 30% of the total Shipyard hazardous waste. Alkaline cleaning solution is used to degrease motor and electrical components under overhaul. The cleaning solution is either used in a dip tank or sprayed on via high steam pressure. Chemical analysis of the spent cleaning solution has indicated high pH and heavy metal content. The waste was normally disposed of through a contractor.

Analysis indicated that a high suspended solids content precluded cost effective recycling of the cleaning solution. Therefore, a pretreatment system was designed to filter, neutralize, and remove oils and heavy metals from the spent cleaning solution. Current microfiltration, ferrous sulphate and oil separation technologies were incorporated. The treated product may be discharged to the sanitary sewer as non-hazardous waste. The treatment residue, which accounts for less than 10% of the original waste volume is disposed of as hazardous waste through outside sources. This system provides a payback of less than one year by offsetting annual disposal costs of over $200,000.

Distillation of Freon and Mineral Spirits

An excess of 50,000 gallons of used Freon solvents and mineral spirits combined were previously disposed of as hazardous waste each year at a cost in excess of $150,000. A series of solvent reclamation stills has been implemented which can recover the used solvents at a high purity level, virtually eliminating the need for disposal. Reuse of the recovered solvents has substantially reduced the need to purchase new solvents, yielding an additional annual cost savings of over **$75,000.** At a cost of approximately $50,000, this system has provided a payback of less than one year.

Metal Pipe Cleaning

Aluminum, copper, copper-nickel, ferrous steel and stainless steel pipe must be chemically cleaned through a multiple step process to remove oxidation and surface contaminants prior to welding and painting. During the process the pipe is rinsed in a water bath between each chemical application. The used rinse water constitutes hazardous waste due to heavy metal and chemical content and must be disposed of through an outside contractor. An alternate rinse process is being designed incorporating countercurrent rinse baths. Excess rinsewater is evaporated, condensed and returned to the final rinse bath. The remaining solids are disposed of as waste. This closed loop system reduces the waste stream from this cleaning process by over 95%.

Hard Chrome Plating Retrofit

An innovative system designed by NEESA was implemented to eliminate the need to dispose or treat rinse water generated by traditional plating techniques. The reversible rack, twin bus bar, zero discharge system uses a mist to rinse parts, returns the rinse water as make up water for the plating bath, and cleans the bath with a special porous filter. This process eliminates the need to dispose or treat used rinse water or dump the plating bath.

Paint Booth Water Treatment

Water utilized as a "curtain" in paint spray booths was traditionally disposed of as waste upon saturation with paint sludge. A system has been implemented to recycle this water. A non-hazardous chemical flocculant is metered into the booth water. The chemical causes the paint sludge in the water to flocculate. The sludge is then easily removed and the water is recirculated in the booth. A 90% reduction of this waste stream has been achieved with this process.

Can and Drum Shredder

This device converts used cans and drums to marketable scrap metal. These containers were otherwise manifested as hazardous waste due to their previous contents. Implementation has resulted in the elimination of 83 tons of waste per year.

Plastic Media Stripping

Numerous paint stripping *Operations* exist throughout the shipyard. A large portion of them incorporate hazardous solvents such as methylene chloride as the stripping agent. With technical guidance from NEESA, PNSY will be implementing alternative stripping using plastic grit that is harder than paint but softer than metal parts. This mechanical blasting process will eliminate handling and disposal of hazardous liquid strippers.

CONCLUSION

Full scale implementation of all the projects described will enable PNSY to easily achieve the goals set forth at the onset of the program. In fact, the CNO goal of 50% reduction by 1992 will be met exclusively through minimization projects in the motor shop, pipe shop, and by solvent distillation alone. The projection shown in figure (2) is based on this information.

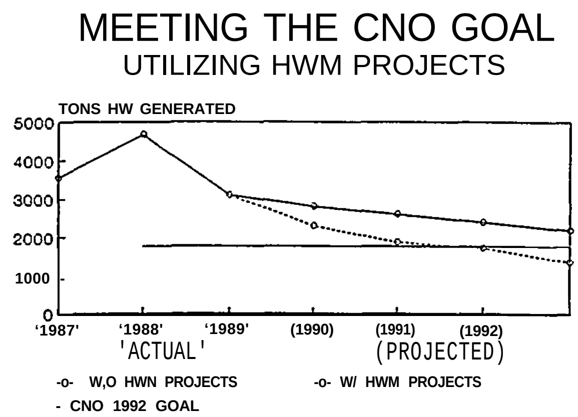

figure 2.

As a result of these efforts, PNSY will significantly reduce generations and amount of hazardous waste going to land disposal, drastically reduce costs associated with disposal, and remain legally responsive to federal, state and local environmental regulatory agencies.

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Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24,1990

The Development of CO_2 Blasting Technology in Naval Shipyards

4B-3

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ABSTRACT

What is CO_2 blasting? CO_2 blasting is a relatively new paint removal-technology that turns liquid carbon dioxide into pellets. The most promising applications are elimination of hazardous waste, dust plumes, and contaminated water associated with the use of slag abrasives.

This paper will describe the process that Naval Sea Systems Command used to take CO_2 blasting from the "talking" stage to implementation in naval shipyards. The process started with a visit from a vendor and ended with a thirty day test of the blasting system.

TEXT

Navy ships bottoms are painted with antifouling paints that contain pesticide ingredients that are used to control attachment and growth of marine animals and plants living in association with structures that are in prolonged contact with salt or fresh water. Significant growth of these "fouling" marine organisms, such as barnacles, seaweed, and algae, can restrict the openings of piping, increase the weight of buoys or other navigational equipment, constrict moving parts such as propellers, inhibit vessel maneuverability, and cause roughness that reduces boat/ship speed and increase fuel consumption. Fouling organisms may damage surface coatings, promote corrosion, interfere with sonar equipment by increasing noise levels, increase maintenance costs, and detract from the appearance of the vessel.

These antifouling paints and other coating systems installed through out the ship require removal periodically. The industry accepted method for coating removal and surface preparation is abrasive blasting using an abrasive slag. These slags must meet the military specifications to be acceptable for use on Navy ships. A list of acceptable slags is maintained by Naval Sea Systems Command. In naval shipyards, paints and other coatings are removed from surfaces and the surfaces are prepared for recoating by abrasive blasting. This process generates large quantities of spent abrasive which is considered hazardous in some states. In addition, work schedules are limited because dust plumes generated by these abrasives are restricted by opacity requirements. National Pollutant Discharge Elimination System (NPDES) discharge permits limit the heavy metals and other constituents that can be leached from the abrasive into water discharged from the dry dock.

We have been attempting to eliminate any discharges from our dry docks thus we have actively pursued any improved method to cut down or eliminate contaminates. Alternative methods of surface preparation tend to complicate the problem. High pressure water blasting and Water-ring abrasive blastina generate additional water treatment problems from leached metals and corrosion inhibitors. Organic abrasives (corn cobs, walnut shells, etc.) eliminate the heavy metals but are dusty and, when confined, present explosive hazards. Performance of the plastic media blast was equal to organic abrasives but the spent abrasive mixed with the removed coating created additional disposal problems.

In July 1987 a vendor provided the Naval Sea Systems Command (SEA 07) with a brochure and a video tape describing the CO_2 blasting process that demonstrated the potential to resolve some of the problem. Blasting with CO_2 does not have any adverse impact on the environment since CO_2 is a naturally occurring gas. Furthermore, this process does not add contaminates to the coating being removed. Only the paint or coating must be disposed of when the evolution is complete. We scheduled showings of the tape for our technical codes and

various management personnel. Each group was pleased with the tape and suggested further evaluations.

We obtained information packets for each of our naval shipyard commanders and for both the Atlantic and Pacific Fleet Maintenance Officers during the month of March 1988. Each packet contained (2) "Blast Cleaning With CO2 ?", (2) "CO_2 Cleanblast" brochures and (1) videotape. These packets provided a brief description of this technology and suggested various uses of the process. Each shipyard commander had their shipyard review the material and provide feedback to headquarters. SEA 07 requested each shipyard not to conduct evaluation tests since we were planning a preliminary evaluation of co2 blasting.

We enlisted David Taylor Research Center to design a preliminary test to determine the effectiveness of this technology. The test consisted of twenty-one panels, with standard navy coatings applied. The panels are listed in Table 1 with a description of the coating applied. Various naval shipyards were included in the test by providing the test panels.

Table 1

Panel No.	Description
1	Light Baked Enamel Coating
2	Heavy Baked Enamel Coating
3	Water Base Fire Retardant Coating w/o primer
4	Water Base Fire Retardant Coating w/Devoe 201 primer
5	Chlorinated Alkyd w/o primer
6	Chlorinated Alkyd w/zinc chromate primer
7	Tank Coating (Devoe 215W)
8	Formula 84/111 Enamel
9	Nil-D-3135 Underlayment w/o primer
10	Mil-D-3135 Underlayment w/Devoe 201 primer
11	150 Series Epoxy Primer
12	150 Series Epoxy Primer w/F121 antifouling paint
13	150 Series Epoxy Primer w/RFE-490
14	Powdered Epoxy Coating
15	Aluminum thermal spray coating with Type I sealer (two coats, top coat only)
16	Aluminum thermal spray coating with Type II sealer (epoxy only, top coat)
17	Experimental epoxy anti-corrosion with sand non-skid
18	Non-skid-Comp, G, Class II Roller
19	Non-skid-Comp, G, Class II Troweled
20	Non-skid-Comp, L, Roller
21	Non-skid-Comp, L, Troweled

The equipment used for this preliminary evaluation was a patented CC2 pellet blasting system. The pelletizer uses 500 lbs/hr of liquid co_2 to produce 250 lbs/hr of pellets by compressing the CO2 flakes with an extruder through an orifice. We used l/S-inch diameter pellets for our test. 1/4- inch diameter pellets are available with a different extruder. The pellets were propelled through a l-inch nozzle at 700-800 ft/sec using 750 CFM of air at 250 psi. Air pressure at the nozzle was 210 psi. The liquid CO2 costs approximately $0.03 to $0.04 per pound. The manufacturer provided the equipment and labor to conduct the test. The test consisted essentially of placing each panel in a vice and blasting a strip across the top of each panel. The time used and the area blasted were recorded. The results are contained in Table 2. These figures are not be used to extrapolate removal rates for larger surface areas, other factors must be included such as fatigue, condition of surface area and shape of the surface. This test determined the feasibility of this process for paints and coating removal.

This preliminary evaluation demonstrated that the CO2 blasting system was not effective in removing epoxy paints, non-skids, or underlayment. The system was effective in removing the softer coatings, such as vinyl antifouling paints, baked **enamels,** chlorinated alkyds, Formula 84/111 enamel, water base fire retardant paints, and tank coatings such as Devoe 215W. See Table 2 for the specific results. Further, the evaluation indicated that the Co2 blasting system should be tested and evaluated in an industrial environment in order to establish removal rates, fatigue factors and safety precautions.

To avoid each naval shipyard testing and evaluating CO2 blasting system, Norfolk Naval Shipyard was requested to conduct an evaluation of CO2 blasting system and report on the various shipyard applications. The evaluation test was designed by Norfolk and consisted of open air blasting and blasting in an enclosed area (a connex box) to simulate an enclosed space aboard ship. From 9 September through 20 October 1989 eighty-three different items were provided by the various shops and blasted. The Shipyard's Safety and Health Office monitored the open air blasting. The Naval Environmental Health Center monitored and sampled the air to assure that the level of oxygen and carbon dioxide did not exceed the acceptable limits. If at any time monitoring results indicated

Table 2

Panel No.	Cleaning Time In minutes	Area cleaned Square inches	Rate Square inches per minute
1	1:04	21	19.7
2	1:03	21	19.7
3	:09	6	40.0
4	:58	6	6.2
5	:15	6	24.0
6	:16	6	22.5
7	:20	6	18.0
8	:20	6	18.0
9	:35	3.8	6.4
10	1:18	7.5	5.8
11	2:05	9	4.3
12	:08	9	67.5
13	1:53	9	4.8
14	2:45	8	3.0
15	:15	9	36.0
16	1:16	9	7.1
17	1:03	6	5.7
18	2:20	9	3.9
19	1:30	6	4.0
20	3:00	8.3	2.8
21	2:06	6	2.9

TABLE 3

LIQUID CO2 CLEANLINESS REQUIREMENTS

The following listed contamination values are to be considered the MAXIMUM permitted unless specifically noted to be otherwise.

COMPONENT	VALUE	TEST METHOD
CO2 purity (min)	*+ 99.9%	Caustic absorption
Oxygen	* 30 ppmv	Trace 02 analyzer
Water (H_2O)	* 32 ppmw	Electrolytic hygrometer
Nitric Oxide (NO) (v)	2.5 ppmv	Color Detector tube/GC
Nitrogen Dioxide (NO_2)	2.5 ppmv	Color Detector tube/GC
Sulfur Dioxide (SO_2)	* 5.0 ppmv	Total sulfur analyzer/QC
Other Sulfur compounds including Hydrogen Sulfide	* 0.5 ppmv	Total sulfur analyzer/QC
Carbon Monoxide (CO) (V)	10.0 ppmv	Infrared analyzer
Volatile H'carbons (v)	*40.0 ppmv	Flame ionization type total h-carbon analyzer
Acetalhyde	* 0.2 ppmv	Gas chromotragph
Heavy hydrocarbons	* 10.0 ppmv	Flame ionization type total h-carbon analyzer
Other toxic materials	none	Gas Chromatograph
Inserts	* 1000 ppmv	Gas Chromatograph
Order	* Free of foreign odor	Sensory

* = Test perfored on vaporized liquid
v = Test performed on vapor in equilibrium with liquid
GC = Gas Chromotgraph with appropriate detector
\+ = Minimum permitted for this value

TABLE 4

REMOVE GREASE FROM CHOCKS FOR A LATHE

OLD METHOD

REMOVE BY HAND USING TRICHLCRIETHANE	
$49.39/LB X .5 LH TO REMOVE GREASE =	**$24.70**
Trichlorethane used 1 ga1/$5.00 per gal =	**5.00**
Disposal of used Trichloroethane	
(1 gal) x ($2.50 per gal) =	**2.50**
Old Method Total =	**$32.20**

NEW METHOD

Remove with CO2	
$49.39/LH X 64 set to remove grease X 1hr/3600 set =	**.87**
CO2 used	
(500 lb/hr) X (64 set) X (1hr 3600 set) = 9 lbs	
(9 lbs) X ($.04/lb C02) =	**.36**
Operating cost	
($20.00/hr.) X (64 set) X (1hr/3600 set) =	.36
New Method Total	$1.59

Old Method - **$32.20**
CO2 Method - 1.59

Total Savings $30.61

1. LH- Labor Hour
2. Non dollar values are rounded to nearest unit
3. Dollar values are rounded to the nearest $.01

oxygen concentrations below 19.5%, all co_2 blasting/ co2 release would cease until such time that ventilation could restore oxygen concentrations to at least 20%. After the first week of operation the Safety Office concluded that the amount of CO2 being released to the environment was not sufficient to warrant constant monitoring.

During the evaluation in the shipyard the blasters were provided personal protective equipment such as: clear plastic face shield, leather gloves, industrial leather footwear, clothing that covered the arms and legs, proper ear protection, safety glasses and for the enclosed area test oxygen monitoring devices that issued an alarm at concentration of oxygen of not less than 19.5%. The test site access was restricted to authorized personnel who were equipped with personal protective equipment and briefed of the potential hazards. Appropriate warning signs were posted for the duration of testing. Additional personal protection was available at the blast site for visitors.

Particular attention to the following parameters were recorded: the square footage of the various items; the time required to clean the item; the quality of work; blast air pressure monitored and adjusted for optimum results; carbon dioxide use; the old or present method of cleaning; and the removal rate of the old method.

Norfolk provided their final report in April 90. A problem with CO2 blasting encountered was contamination of the liquid CO_2. The CO2 needs to be food quality and sampled each time a new shipment arrives. The vendor (providing the CO_2) should certify that the liquid CO_2 is food grade and provide proof with each shipment. Contaminated CO2 caused the equipment to malfunction and delayed the test for a couple days. Table 3 provides the maximum contamination values permitted unless otherwise specifically noted.

The labor hour rate for each shop in a naval shipyard is determined by the Comptroller section and is different for each shop. The rate for individual shops is revised two or three times per year to reflect the actual cost of doing business ie. lights, steam, water etc.

Table 4 provides an example of the cost analysis used in the evaluation. The labor rate used in this example is $49.39 per hour.

CO_2 blasting will remove rust, grease and other coatings from machined parts and not destroy the machined finish. A near white metal blast (SSPC 10) is nearly impossible to obtain. The CO_2 blasting process will provide adequate surface preparation for paint application. (Provided the material had been previously blasted).

The best removal rates were obtained when the abrasive stream was perpendicular to the surface being cleaned. Additional nozzles are being developed for special uses, i.e., short, wide, and narrow nozzles.

Additional tests in conjunction with the Army, Air Force, Marine Corps, Naval Air systems Command and other activities are being conducted. The Air Force conducted a test using higher pressure and a different vendor to remove paint from their "thin skinned" airplanes. Paint on airplanes is considerably harder than paint on a ship. Norfolk Naval Shipyard is the lead activity for evaluating CO_2 blasting. This technology has proven successful on "thick skinned" applications.

The blasting in confined spaces such as bilges, tanks and voids has not been adequately investigated to date. Our evaluations have shown potential for savings in both labor and disposal costs. The only disposal cost is for the substance removed from the surface. The CO_2 returns to the atmosphere with little or no effect on the environment.

CO_2 blasting technology provides a good tool for our shipyards to use. This tool is only one of many that will provide adequate coating removal. CO_2 blasting has the potential to eliminate waste and improve working conditions. We Plan to implement this technology in all eight naval shipyards.

As you can see any new or different technology requires a dedicated effort and adequate testing to ensure a quality product. The process works.

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel. Milwaukee, Wisconsin. August 21-24,1990

Modeling and Transfer Of Product Model Digital Data for the DDG 51 Class Destroyer Program 5A-1

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INTRODUCTION

Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) technologies offer significant benefits in the design, construction, and life cycle support of today's complex Navy ships. CAD provides the capability to create three dimensional (3D) product models which can realistically represent geometry and associated design data of the ship prior to construction. Building of a computer model of the ship prior to construction reduces interferences and improves design accuracy and completeness. The 3D computer models consist of geometry and associated design data for components and systems, and provide a tool to design and evaluate form, fit, and function. Efforts such as interference detection and resolution, simulated walk-throughs, change-impact analysis, and improved production sequence planning can be conducted concurrently with design development. Detail design drawings, manufacturing sketches and Numerical Control (NC) instructions can be developed and extracted directly from the design database. This reduces duplication of data, saves time, and lowers costs - for both the construction of the ship and the life cycle maintenance functions that follow. The most significant benefits of 3D CAD/CAM methodologies as applied to complex Navy surface combatants are improved design and manufacturing accuracy and consistency, which in turn result in savings in production time and cost. On the U.S. Navy's ARLEIGH BURKE (DDG 51) Class AEGIS Destroyer program, CAD/CAM technology is being implemented to take full advantage of these savings.

BACKGROUND

Computer Aided Design is a rapidly developing technology in the shipbuilding industry. In 1985 Bath Iron Works (BIW) and Gibbs and Cox planned to execute detailed design for DDG 51 in 3D CAD. However, the necessary resources and capabilities did not exist to successfully complete the plan and BIW reverted to manual design. To support the transition of DDG 51 design to CAD it was necessary to create or acquire the following:

- Processes - adequately piloted and tested methods.
- Software - the necessary application computer programs and relational database management software.
- Hardware - the required distributed and integrated work stations with sufficient processing speed.
- Trained personnel

Since the beginning of the program, Bath Iron Works (lead yard) , Gibbs and Cox, and Ingalls Shipbuilding (follow yard) have built their CAD capabilities to the point that their combined resources have made it feasible to model the ship. Based on this capability the AEGIS Destroyer Program initiated a project to move DDG 51 to a CAD based design.

The project objectives are to allow construction of ships in two yards from a single design; to improve the movement of construction data between the shipyards; and to create a digital information base for life cycle support.

The project required the achievement of two tasks, transferring the existing paper design into CAD and creating the capability to transfer intelligent 3D product models.

This paper addresses the specifics of the parallel efforts in CAD modeling and Digital Data Transfer (DDT) implemented by the AEGIS Destroyer Program. The paper covers background information, task objectives, problems encountered and their resolution, current status and future plans. This project represents a significant cooperative effort

between the U.S. Navy's AEGIS Destroyer Program, BIW, Ingalls, Gibbs and Cox, and General Electric/Government Electronics Services Division.

PRODUCT DATA MODELING

Approach

The Program Manager in the AEGIS Destroyer Division (PMS 400D) initiated a project to translate the paper design information into 3D CAD product models in a phased program over a 36 month period. The product model consists of all information necessary to define the detail design for manufacture. The product models will be used to generate fabrication and installation drawings, supplemental drawings, NC information and templates. The 3D CAD models will also be available for use in the contract and detail design stages of future flights of the DDG 51 Class.

The CAD modeling effort is intended to create a database to support construction. The 3D design models will be used to check and clear interferences and, after validation against the manual design control mats and issued construction paper, will replace the paper design control mats as the design basis for the class. Accomplishing the actual modeling requires the resources of both shipbuilders and the Class Combat Systems Engineering Agent, General Electric (GESD). There are seventy-seven Design Zones in the ship and a plan was laid out for concurrent work on an initial subset of twenty-six zones. These twenty-six zones were selected because they are the most complex and represent the largest initial payoff.

The AEGIS Destroyer Program tasked Bath Iron Works and Gibbs & Cox with modeling eleven Combat Systems zones including the Combat Information Center (CIC), Radio Central, and the Pilot House. General Electric was tasked to provide the combat system components as library parts to be transferred to Bath and used directly in the models. Ingalls Shipbuilding was tasked with modeling the fifteen zones comprising the auxiliary and main machinery spaces. Both modeling efforts are shown in Figure 1. Model content and library part standards were developed concurrent with this work to insure the resulting. models would meet the needs of both shipbuilders and the Navy. The overall 3D Modeling Process is shown in Figure 2. A graphical depiction of the steps involved in the replacement of manual drawings with CAD drawings is shown in Figure 3. Bath Iron Works as lead yard is tasked to process the resulting models to replace the existing paper design control mats. The approach depends on the ability to effectively transfer 3D product model information between the shipbuilders.

Needs and Capabilities

In all design and manufacturing environments, there is a pressing need to improve the quality, usability, timeliness and accessibility of engineering, design, and production data. This is especially true within the shipbuilding industry. Navy surface combatants are very complex, have long procurement cycles, incur significant design changes, and have long maintenance and overhaul life-cycle requirements.

Introduction of 3D CAD into the design and construction process as early as possible minimizes the duplication of information. For the existing DDG 51 design the appropriate point of transition to CAD is the Design Control Mat (DCM). The DCM represents the culmination of the composite design process, and marks the starting point for preparation of construction products. The DCM is also the document used to incorporate design changes.

A primary benefit of 3D CAD is the availability of accurate and consistent data for Computer Aided Manufacturing (CAM). The definition of CAM in this context is all manufacturing data used by Production, not just limited to the classical definition of Numerical Control (NC) data. Realization of the full potential that CAM offers in production requires that all construction information originate from the same 3D CAD database. This information includes: drawings and material lists; NC tapes; templates; and jigs and fixtures. CAD can also provide additional information such as improved production sequence planning graphics, which are not practical otherwise.

3D product models, within the context of CAD/CAM, include definition of:

- Object type (e.g. components, fittings, pumps, valves, cableways, etc.)
- Detail, clearance and maintenance geometry
- Location
- Orientation
- Connectivity information
- Catalog (material)

- Instance identification (specific occurrence of the part)
- Revision identification (latest change to the part)

Additional information such as zone, discipline, and system is also stored within each model. This data is sufficient to control the design configuration, and may be integrated with other material or production systems. For example, this data may be tied to a material catalog through the catalog number, and, to material management systems through the instance identifier (unique piece or part number identifier) and catalog number. The CAD product model is then the central source of material identification for quantity, type, and fabrication and installation data. Additional material data for definition of work packages, construction stage and sequence, shop floor control, and inter-trade routing (e.g. the production bill of material) should supplement the CAD engineering/design bill of material on a separate but linked Material Management System.

Utilizing well-defined processes and standards, CAD linked with engineering data management tools offers the opportunity to integrate the entire shipbuilding process. Product models, tied to a relational database which defines the material incorporated in a design, provide: the basis to drive the yard detail material ordering system: input to the Navy supply support system; and input for technical publications and training.
In like fashion, a relational database, which defines process information associated with the installation of each component, feeds the materials control system and the production planning system. A separate but integrated file tracks all the drawings associated with any model and flags them for revision when changes are made to the model.

To support engineering efforts of the shipbuilding process, the use of Computer Aided Engineering (CAE) is being developed. As engineering changes are introduced in the class and revised ship support systems are required, the use of analysis programs which operate directly with the CAD data greatly enhance the system engineering function. Controlled use of the CAD database insures the analysis matches the actual system configuration. Development of on-line engineering analysis tools offers the opportunity to improve both the quality and the efficiency of the design engineering process.

The implementation of these CAD/CAM technologies has started, but remaining work is formidable. While the use of 3D CAD may not make the individual designer more efficient, the resulting data used to drive the entire production process makes the CAD system a powerful tool.

Development of capabilities like these is critical to achieving the quality improvements and cost savings needed to make continued product improvement possible and affordable. The AEGIS Destroyer Program is advancing the development of these capabilities and their introduction into the program.

shin Life Cycle Support

Ship configuration information in digital form offers advantages for life cycle support since the product model data can be transferred electronically to support activities such as the planning yard, the U.S Navy Supply System, and the various in-service engineering agents. Improvements can be made in: the process of overhaul and repair planning (installation sequence); maintaining a more accurate and up-to-date configuration; and providing more accurate fabrication and installation drawing and material information at time of repair or overhaul. The DDG 51 CAD modeling program provides the initial digital information, while the Digital Data Transfer program establishes the basic standards for content and format to accommodate the information transfer.

Model Construction Benefits

The process of building models has demonstrated many of the benefits CAD offers. Model construction is accomplished by assembling all the construction drawings and open change notices to establish a dated baseline. Pipe, ventilation, and electrical models are built for each ship work breakdown structure (SWBS) for the zone. Very large or complicated models may be subdivided into port, center, and starboard segments. In the case of Combat Systems and hull outfitting, models are segregated by overhead or deck within the zone. Both the fabrication and installation drawings are used to construct the model.

This has proven to be an excellent consistency check between the fabrication drawing and the installation drawing. Discrepancies

are reported to the lead shipyard, which has responsibility for maintaining drawings. Corrections are made to manufacturing aides before manhours and material are spent on unusable fabrications. The resulting savings to the program have offset the cost of the modeling effort.

Model Processing Benefits

Once the individual distributed systems models have been constructed for a zone, they are merged for interference checking. Each interference is analyzed as being a problem interference or an acceptable interference. In certain cases, collisions (two objects or surfaces occupying the same space) are reported as interferences but may be acceptable. A watertight penetration of a pipe through a bulkhead is an example of an acceptable interference. Once the reported interference is classified as to its acceptability, a CAD generated sketch is created that reflects those considered to be a problem. If detailing for manufacturing aids is in process, the problem is reported to the detailing group for resolution prior to issuing the aids and drawing to manufacturing.

Post-Design Information

A major impact the modeling effort has on manufacturing will be the reduction of interferences. Ship construction schedules require many parts of the design to take place simultaneously. This leads to the possibility of pipes, ventilation ducts, and/or wireways being routed into the same location and interfering with equipment. While the composites or design mats worked toward the elimination of these occurrences, some undetected interferences still manage to slip into the manufacturing process. It is widely accepted that the elimination of interferences and their corresponding costs is a major benefit from 3D modeling during the design and manufacturing processes.

Another major benefit of CAD modeling is the ability to extract data to satisfy the manufacturing criteria of the specific yard. These criteria tend to be determined by the equipments in a specific yard and how these equipments are used. Extraction of Numerical Control (N/C) data can, when properly formatted, drive burning or bending machines. After being entered into the product model and checked, data is programmatically extracted.

Another feature is the ability to extract specific task-oriented drawings where the craftsman receives only that information required to perform his job. The craftsman does not have to work from a large, complicated and cluttered design drawing. Figures 4, 5, 6, and 7 are examples of the types of drawings and bills of material that can be extracted from a product model. Projected cost benefits from other uses of this data have been identified and efforts are underway to develop their capabilities. These include uses such as simulated walk-through and change impact analysis.

Planning can clearly benefit from access to this information. By testing "what-if" scenarios, size and sequence of installation can be optimized while viewing the actual data in three dimensions. Further, different views can be utilized to represent the configuration of the ship as it is being manufactured rather than the configuration it will ultimately assume. Many fabrication or installation drawings may be plotted in an inverted position that enables a craftsman to view his product as it appears to him. Drawings showing downstream work will show the product flipped to a ship orientation for final integration with other ship components.

costs

This project has required a significant investment in personnel, hardware, training and processes. While the AEGIS Destroyer Program has carried the majority of the costs, each participating organization has had to dedicate management resources and make a corporate commitment to implement new technology. The effects of this project will permeate through each organization and in some instances fundamentally change methods of operation. The challenge is to manage the changing methodology and CAD based ship construction.

Status

Actual 3D modeling and drawing development work is well underway with eighteen (18) zones completed by both shipbuilders and the majority of the library parts completed by General Electric and BIW. Model transfer from Ingalls to Bath is in process, and the AEGIS Destroyer Program has tasked both shipyards to create construction products from their models. Extensive work remains to be done to integrate models as they are built and to transition to 3D CAD-based design both within each yard and between the yards for the DDG 51 Class, but the

achievements thus far leave no doubt of future success.

OUTFITTING DATA TRANSFER PLAN

Background

Transfer of the product models and use by both shipbuilders, combat systems design agent and the Navy is required to achieve the full benefit of using CAD. Each yard uses CAD systems for outfitting and structural definition which are different within and between the yards. Bath Iron Works uses Computervision for outfit and AUTOKON for structure; Ingalls Shipbuilding utilizes Calma for outfit and SPADES for structure. In order to utilize these combined resources, it was necessary to develop a means of translating digital data between their proprietary and incompatible data formats.

Objective

The AEGIS Destroyer Program's overall objective in this effort is to implement a two-way transfer of Outfit product models between the BIW Computervision (CV) System and the Ingalls calma System, as illustrated in Figure a. Both BIW and Ingalls had previously developed the capability to transfer structural models from their respective structural to outfit systems.

Overall Approach

The AEGIS Destroyer Program tasked BIW and Ingalls to develop a mutually agreed-upon plan of action. In order to implement a digital data transfer capability between dissimilar CAD/CAM systems, several steps are required:

1. Models must exist or be created
2. Data to be transferred must be defined
3. Format of the transfer medium must be defined or selected
4. Transfer computer software must exist or be created
5. Testing must be accomplished to validate the process
6. Transfer procedure must be defined and implemented

When the AEGIS Destroyer Program initiated this project in January 1988, and both BIW and Ingalls already had significant 3D modeling experience. Step 1 was completed by building models of three selected zones to use in the test phase. Steps 2 through 6 represent the basic scope of the DDT project as described below.

The management and technical approach for DDT included consideration of the following requirements and constraints:

Requirements.

- Transfer of engineering and design product model intelligence
- Achievable and verifiable transfer accuracy
- Configuration accounting
- Elective component substitution
- User friendly translator usage
- Minimized transfer file data volume
- Minimized translator processing time
- Minimized translator software maintenance

Constraints.

- Large number of components contained in 3D product models
- Complexity of the component relationships defining distributive systems
- Volume of component non-graphic (attribute) data contained within the 3D product models
- Similarities and differences between component libraries and database constructs across the two CAD/CAM systems
- Current state of the art in Initial Graphics Exchange Specification (IGES) and Product Definition Exchange Specification (PDES) development and implementation.
- Current state of the art in database management systems
- Existing manual drawing transfer between the two shipyards

Data Transferred

BIW and Ingalls completed definition of the data to be transferred for distributive systems early in the project. This definition was reviewed, modified, and approved by the AEGIS Destroyer Program, BIN and Ingalls for all disciplines. Reference 1 provides a listing of the data transferred and contained in the product models. The effort involved in the definition and concurrence which this document represents was extensive. It involved a significant review of the modeling practices of both organizations and an in-depth understanding Of the internal architecture of both CAD/CAM systems.

Neutral File

The next major step in DDT was definition and selection of the format for the transfer. The AEGIS Destroyer Program, BIW and Ingalls mutually explored the following alternatives:

1. "Flavored" Initial Graphic Exchange Specification (IGES) or Standard IGES. "Flavoring" is the term used to define the process of augmenting the shortcomings of the implemented standard in order to adapt it to the required task.
2. Defer until the completion of Product Definition Exchange Standard (PDES) and its commercial implementation.
3. Development of direct translators by a software developer specializing in CAD direct translators.
4. Use of a neutral file that defines object data.

Option 1, the IGES approach was not selected because both shipyards were using and developing CAD applications that were object oriented instead of entity oriented. PDES is still in its definition phase and selection of Option 2 would have required several years delay in implementation of a production translator. Option 3 would have required the development of direct translators. They were not available for 3D product model information and would not have met the Navy's need for flexibility in future use or expansion. Option 4 was selected by the AEGIS Destroyer Program for capability, flexibility for future expansion, and ability to create within the time available.

Object Transfer

The use of an object oriented neutral file (Option 4) offered significant advantages in reducing the size of the transfer files. More importantly, the object transfer approach retained the intelligence contained in the original model. In this context, object (or component) is an BVAC shape, a piping valve, a piping fitting, an electrical cableway hanger, etc. Figure 9 illustrates the object approach versus the IGES approach. As defined by IGES the desired object would have been geometrically constructed on the receiving system as a series of separate lines, arc, etc., rather than an object with associated properties and intelligence.

Bath Iron Works was tasked to outline the translator specification. BIW and Ingalls divided responsibility for writing the specifications - each wrote different sections and exchanged work. The end result was the "DDG 51 Class Digital Data Transfer Project Functional Specifications" Reference 2. After the final specifications were agreed to by both shipbuilders and approved by the Navy program office, each shipbuilder developed or subcontracted the computer programs specific to his system.

BIW and Ingalls both use an object modeling approach on their CAD systems and each has the capability to attach design attributes to objects, as well as a property file capability. Attributes consist of information such as catalog number, piece/part number, fitting type, etc. Property files contain geometric data that allow an object to be graphically displayed, and non-geometric data such as catalog number (link to model), description, weight, and a specification number that describes the object. A means was developed to correlate objects between systems. In the case of pipe and purchased parts for BVAC and electrical, it was determined that catalog numbers could define the object. For manufactured items (HVAC shapes, flanges and gaskets; penetrations; hangers; cable paths, etc.) a shape table was developed that defines the object. Each component was assigned a classification that defines the discipline and either the catalog number or the shape table to define the object. To complete the process a catalog cross reference file was developed which correlates the Ingalls and BIW catalogs and provides orientation normalization between the CV and CALMA systems.

Class Librarian and Parts Transfer

The testing of the translator was based on the transfer of a common test zone modeled at both yards. Use of the object oriented approach requires the existence of: (a) equal part libraries at both shipyards, or, (b) development of the capability to digitally transfer library parts. Early in the project, it was determined that while the libraries for such items as piping were similar, certain DDG 51 specific equipment items existed only on the BIW system.

Where library parts did not exist at Ingalls, the yards were tasked to create the necessary computer programs and procedures to transfer the parts from BIW. The approach chosen was to create a procedure file defining the

component at BIW, and to create software to read the file at Ingalls and automatically rebuild the library part in the CALMA system. The capability was based upon the use of seven basic graphic primitives that were common to both CAD systems. Figure 10 represents a sample transferred part. With the capability to transfer parts came the opportunity to establish a standard library for the DDG 51 Class. BIW was tasked to act as the Class Librarian. The library parts transfer capability is in use between BIW and Ingalls. Full two-way part transfer by means of the procedure file is under development.

Life Cycle Support

The DDT project is concentrating on three aspects of CAD information to insure its ability to support future class logistics: standards for zone model content, library part content and the transfer process. These efforts are intended to be consistent with the developing Product Definition Exchange Standard. The content standards will ensure that the information contained in the models and libraries will support design, construction and life cycle support needs. By working with the PDES group, the transfer products are being developed to support data transfer both now and in the future.

Testing and Results

The translator software was developed and extensively tested by both shipyards. The overall process is illustrated in Figure 11. Both shipyards created a test model for each of three disciplines (piping, HVAC and electrical) for a common zone. First, each model of each discipline was given an internal loop test. Then, these models were transferred from their source yard to the receiving shipyard, processed both in and out of the receiving shipyard's translator, sent back to the source and reprocessed to create a model. This full-loop test was sufficient to determine any deficiencies in the software.

Functional software was developed and tested for intelligent 3D model bi-directional transfer between CV and Calma for piping, HVAC and electrical objects. The results are illustrated in Figures 12, 13, 14, and 15. These isometrics are representative of the translator capability and were created during the testing phase.

Status

The translator software is operational and in use between the shipyards. An additional phase of translator development is ongoing to add capability for piping and vent hangars, waveguide, holes, certain foundations, and outfit and furnishings. When complete in late 1990 the translators will be capable of moving complete product models.

STRUCTURAL DATA TRANSFER

Approach

The objective of this effort was digital transfer of 3D structural design models generated on AUTOKON or SPADES from one system to the other while retaining their topology, intelligence, and lofting capability. Ingalls Shipbuilding, Inc., a SPADES user, and Bath Iron Works, an AUTOKON user, were tasked by the AEGIS Destroyer Program to produce a joint plan of action to develop software to accomplish this transfer. A system specification was written entitled "Autokon <--> SPADES Model Communication System" Reference 3.

Cali and Associates (developers and marketers of SPADES) and Autokon CIM, Inc. (developers of Autokon and part of Kockums Computer Systems A/S) were the two firms subcontracted through Ingalls to develop the software. The approach taken was to create a neutral file containing the data elements necessary to define all required structural objects. The software programs which generate and use the neutral files were called translators. An overview of the links between the two systems is depicted in Figures 16 and 17.

NEUTRAL FILE

The translator/neutral file approach was selected for structure for the same basic reasons that it was selected for the outfit system. The goal was to transfer recognizable objects complete with intelligence and attributes. Commercially available implementations of IGES would have limited the transfer to a collection of points, lines, and arcs comprising the graphic representation of the objects and would not have fulfilled the requirements of the transfer. By utilizing the translator/neutral file approach, the intelligence of the original model was captured and lofting capabilities were retained. Further, it was felt that an IGES file based on simple entities. (lines, arcs, points, etc.) would have been prohibitively large to store and/or

process in a timely fashion when applied to models the size of those being considered for transfer.

Partial Transfers

A requirement of DDT is to be able to transfer only a portion of a given design zone, as opposed to the practice of transferring an entire zone with each exchange. To support this requirement, the concept of the "design window" was implemented in each CAD vendors' system. This feature did not exist on either system and it provided a means of specifying boundaries for the design zone to be transferred.

The design window is a 3D subset of the design zone whose contents are to be transferred. It allows the user to send/receive only the desired portion of a zone, for example, a space where additional structure has been inserted after the entire zone has already been sent or received at the other installation. This concept prevents having to re-send an entire zone in order to pick up only a small area of change.

configuration Management

Closely related of partial transfers is Configuration Management. The partial transfer capability highlighted the need to track the status of previous transmittals of the structural model of the design zone. Partial transfers must address what data has already been sent, what has not, and what has changed between transfers.

By means of a catalog, the translator keeps track of the structural objects being transferred, bypassing objects that have already been translated and passing only those items which are new or changed. A report is generated by the translator with each transfer, thereby documenting the zone's transfer status.

Status

The translator software is operational. There are two translator programs; one installed and running on the Prime computer at BIW and the other installed and running on the IBM 3090 at Ingalls. Translator capability is planned for inclusion into the next formal release of the two CAD systems by their respective vendors.

TRANSLATOR COSTS

Outfit

The outfit translators are custom software packages owned by the AEGIS Destroyer Program. The full cost of development and the cost of maintaining the translators is the responsibility the AEGIS Program. Unlike translators based on national standards the CAD system vendors do not have any responsibility for ensuring compatibility with their new software releases. This was the cost of acquiring a transfer capability sufficient to the needs of the program.

Structural

The structural translators were developed under AEGIS Destroyer Program funding but are the responsibility of the CAD vendors to maintain. Because of their unique structure and the lack of IGES translators in this area the vendors found it to their advantage to assume maintenance responsibility and offer the capability in their respective CAD programs.

ISSUES

The transition to 3D CAD design and electronic data exchange has introduced technical and management challenges. The Project has anticipated many of the issues solved them by the basic approach. Others have been solved in concept but remain to be proven in production. Four of the open issues are configuration management, model completeness, yard practices, and on-line inter-yard CAD access.

Configuration management is both a technical and management issue. Technically the challenge is to establish and maintain positive control of product models and their derived products as they are modified during design development and engineering changes. For management the challenge is to efficiently transition the configuration management organizations from paper to electronic data. The AEGIS Destroyer Program is using information modeling as a basic tool in attacking this issue.

The AEGIS Destroyer Program established zone model content and library part content standards as the tools to solve model completeness issues. The information incorporated in a model determines it's usefulness for design, engineering analysis, construction and future logistics

support. The DDG 51 Program defined the standards on the basis of current practices and projected class support needs. As the models are placed in use the need for more or different information will surface and the standards will be modified as needed.

Each yard has construction practices as well as CAD modeling practices which are different than the other. The differences in modeling are often the result of construction process differences. Shipyard management and the DDG 51 Program standards are the basic tools used in resolving the impact of these differences on the data exchange process. The effectiveness of management in dealing with problems in this area will have a significant impact on the benefits realized from this program.

On-line inter-yard data access is a capability which is important to efficient use of the DDT Project now and will become more important as more of the ship is placed in CAD. The ability to access the latest data immediately prior to releasing work packages could provide significant savings to the construction program. The principle issue is security. Each yard is concerned with the security of their computer data for yard management and performance. While access to CAD would not necessarily require access to shipyard management systems, it is feared that internal networking could allow the competing shipyard to acquire critical business sensitive information. This issue is a management problem currently under review by the shipbuilders.

These issues all contribute to Engineering Data Management. Integrating the many separate data systems which have been created within the shipyards over the years and transitioning to the full use of electronic data for all design and construction support functions are significant management challenges. While tools to attack the problems are available in the form of local area networks, wide area networks, and Engineering Data Management Software Systems implementation will require time and innovation.

These and other issues will be dealt with and solved by the DDG 51 Program. The solutions instituted will consider both the current and projected needs of the AEGIS Destroyer Program.

SUMMARY

The U.S. Navy's AEGIS Destroyer Program established this project to take advantage CAD/CAM in ship construction. Accomplishments and benefits have been significant. Twenty-six zones of the ship have been divided between the shipbuilders for modeling and a plan is being pursued to complete modeling for the remainder of the ship. The combat systems engineering agent has been tasked to provide contract level 3D models of the combat system spaces and library parts for all combat system components. These products are being used within the shipyards to support construction.

The end result of the modeling effort will be interference-free digital design product models. These will replace the traditional design control mats. The product models will also be transferred to each shipbuilder where manufacturing information will be extracted.

The DDG 51 Digital Data Transfer project has put in place a basic translator that supports the exchange of product models. It provides the required path to allow full use of the product models for all program participants.

Actions taken to improve the long term use of the product models and the DDG 51 Digital Data Translator include:

- Establishing Library Part and Zone Model content standards.
- Establishing configuration accounting requirements and procedures.
- Completing Library of Parts for DDG 51 Class (i.e. all valves, combat system components, pumps, motors, etc.)
- Interfacing the data transfer efforts with groups involved with the establishment of national standards for IGES and PDES.

The U.S. Navy's AEGIS Destroyer Program has established long term goals for further development and exploitation of the technology implemented on this project. The DDG 51 DDT translators require further refinement and the use of product model information is just beginning to be developed. The work remaining is significant and the goals have been time phased over several years. The work done to date positions the AEGIS Destroyer Program to take full advantage of CAD and CAM during

construction and to realize many of the benefits of Computer Aided Acquisition and Logistics Support (CALS) over the life of the Class.

ACKNOWLEDGMENTS

The U.S. Navy's AEGIS Destroyer Program could not have successfully completed this project without the help of these key contributors:

Bath Iron Works Corporation
Ingalls Shipbuilding
Gibbs and Cox
General Electric, Government Electronics Systems Division
Cali and Associates
Kockums Computer Services
Calma Corporation
Prime/Computervision Corporation

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3. "Autokon <--> SPADES Model Communication System", Rev 8, November 1989.

3D CAD MODELING
(INITIAL ZONES FOR MANUAL TO CAD CONVERSIONS)

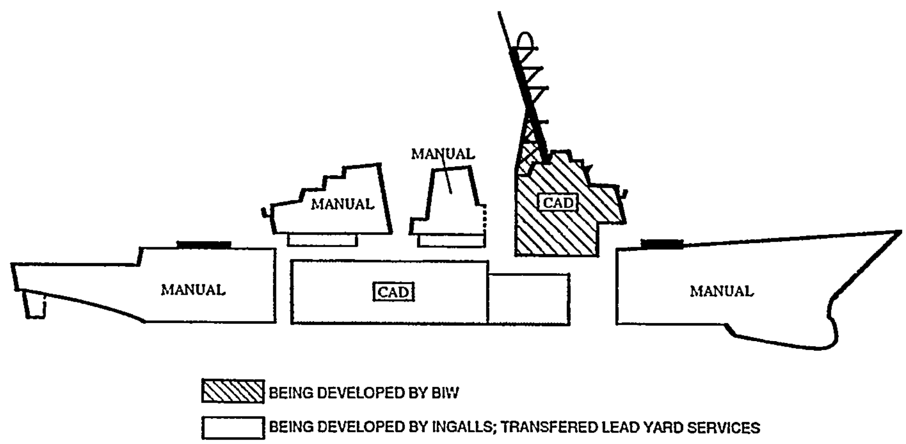


FIGURE 1

3D CAD PROCESS

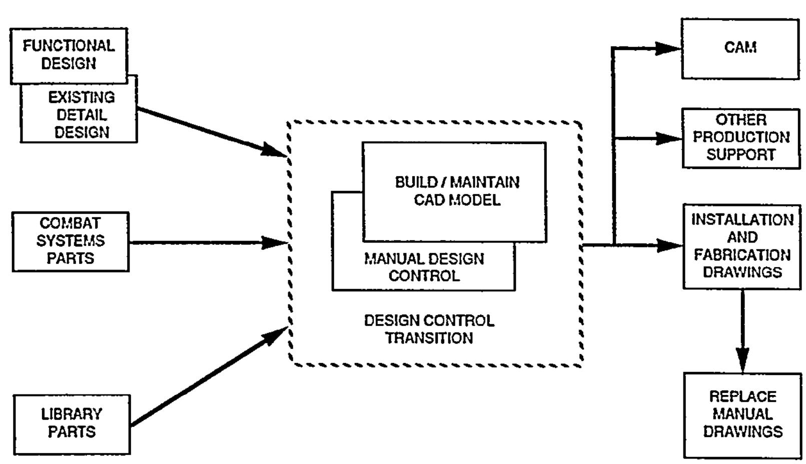


FIGURE 2

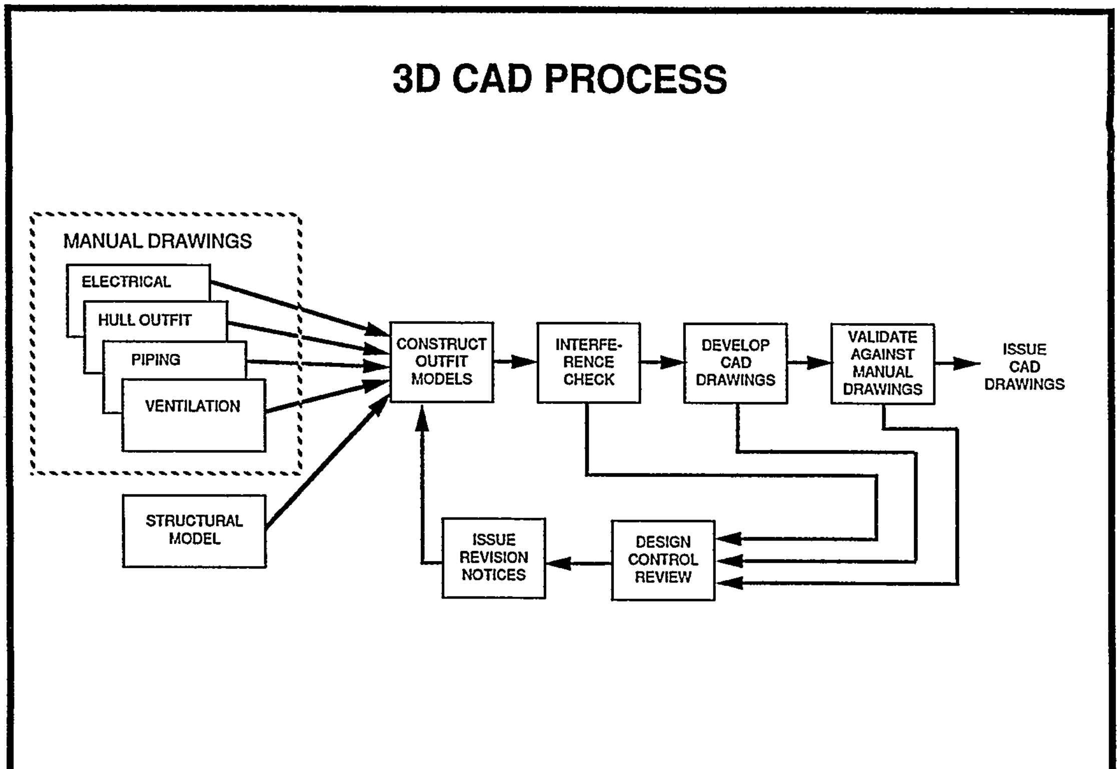


FIGURE 3

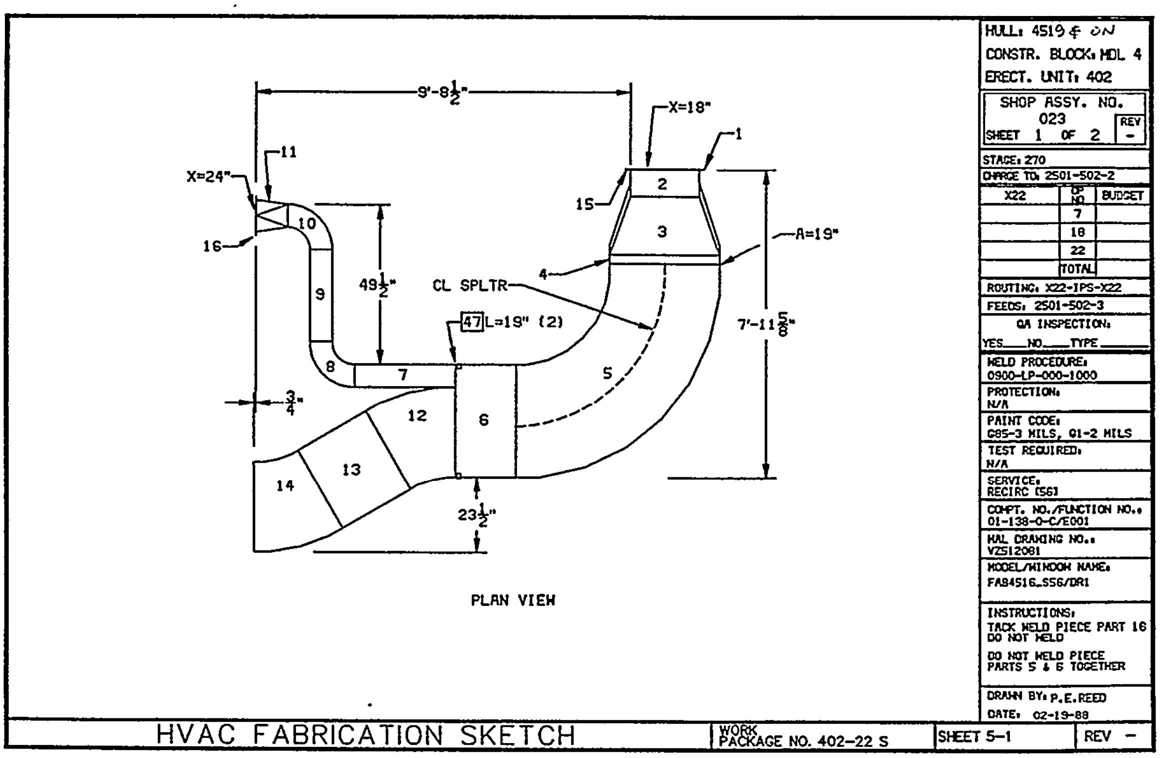


FIGURE 4

HULL: 4519 & ON
CONSTR. BLOCK: MDL 4
ERECT. UNIT: 402
SHOP ASSY. NO. 023 REV -
SHEET 2 OF 2
MODEL/WINDOW NAME: FAB4516_SS6/DR1
NOTES:

FN/NAL NUMBER	QTY	DESCRIPTION	SOURCE NUMBER	MATERIAL	MAT REQ NO	STORE RM LOCATION	STATUS
27/7-11	22 SF	.050"THK SHEET (AA)ALY 5052 TEM H-32 QQ-A-250/8 FOR NHT AL DUCT UP TO 18"	9535-DA0-621354 (VLD512081)	AL ALY			
28/2,12-14	41 SF	.060"THK SHEET (AA)ALY 5052 TEM H-32 QQ-A-250/8 FOR NHT AL DUCT 18-1/2"-30"	9535-DA0-621355 (VLD512081)	AL ALY			
29/3-6	101 SF	.080"THK SHEET (AA)ALY 5052 TEM H-32 QQ-A-250/8 FOR NHT AL DUCT ABOVE 30"	9535-DA0-621357 (VLD512081)	AL ALY			
57/1,15	1 EA	28"X14" FLANGE ASSY SP000030-7126 AL NHT TO AL SPOOL	0000-SP0-307126 (VLD512081)	AL ALY			
87/16	1 EA	10"DIA FLANGE ASSY SP685022-1715 AL NHT TO AL NHT	6850-SP0-221715 (VLD512081)	AL ALY			
47	1 EA	HANGER ASSY LIGHTWEIGHT SP685035-0011 AL NHT DUCT TO AL STRUCTURE	6850-SP0-350011 (VLD512081)	VARIOUS			

HVAC FABRICATION SKETCH (B.O.M.)	WORK PACKAGE NO. 402-22 S	SHEET 5-2	REV -

FIGURE 5

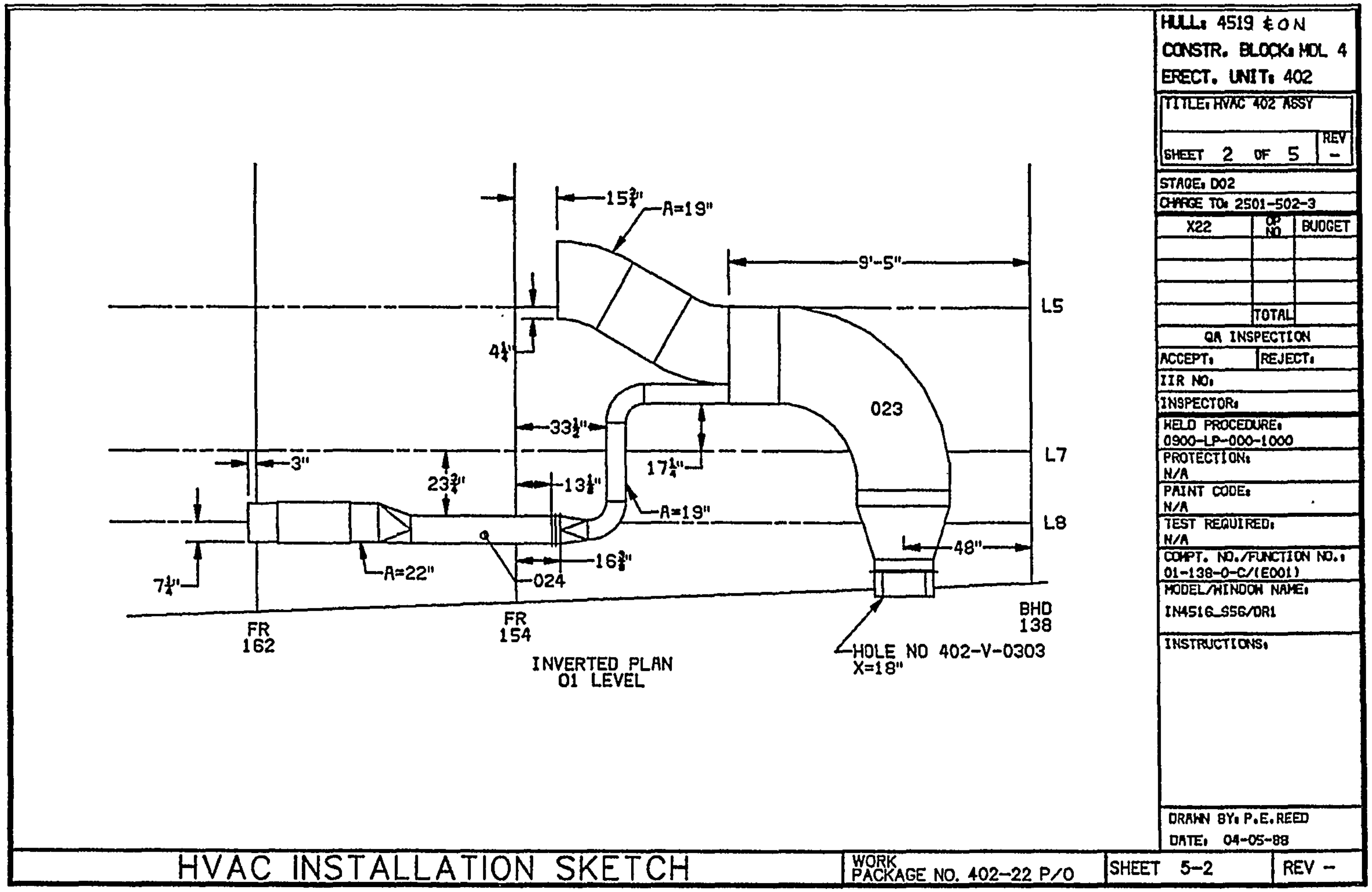

HULL: 4519 ℄ O N
CONSTR. BLOCK: MDL 4
ERECT. UNIT: 402
TITLE: HVAC 402 ASSY
SHEET 2 OF 5
REV -
STAGE: D02
CHARGE TO: 2501-502-3
X22
OP NO
BUDGET
TOTAL
QA INSPECTION
ACCEPT:
REJECT:
IIR NO:
INSPECTOR:
WELD PROCEDURE: 0900-LP-000-1000
PROTECTION: N/A
PAINT CODE: N/A
TEST REQUIRED: N/A
COMPT. NO./FUNCTION NO.: 01-138-0-C/(E001)
MODEL/WINDOW NAME: IN4516_SS6/DR1
INSTRUCTIONS:
DRAWN BY: P.E.REED
DATE: 04-05-88
15¾"
A=19"
9'-5"
L5
4¼"
023
33½"
17¼"
L7
3"
23¾"
13¼"
A=19"
L8
48"
7¼"
A=22"
024
16⅜"
FR 162
FR 154
BHD 138
INVERTED PLAN
01 LEVEL
HOLE NO 402-V-0303
X=18"
HVAC INSTALLATION SKETCH
WORK PACKAGE NO. 402-22 P/O
SHEET 5-2
REV -

FIGURE 6

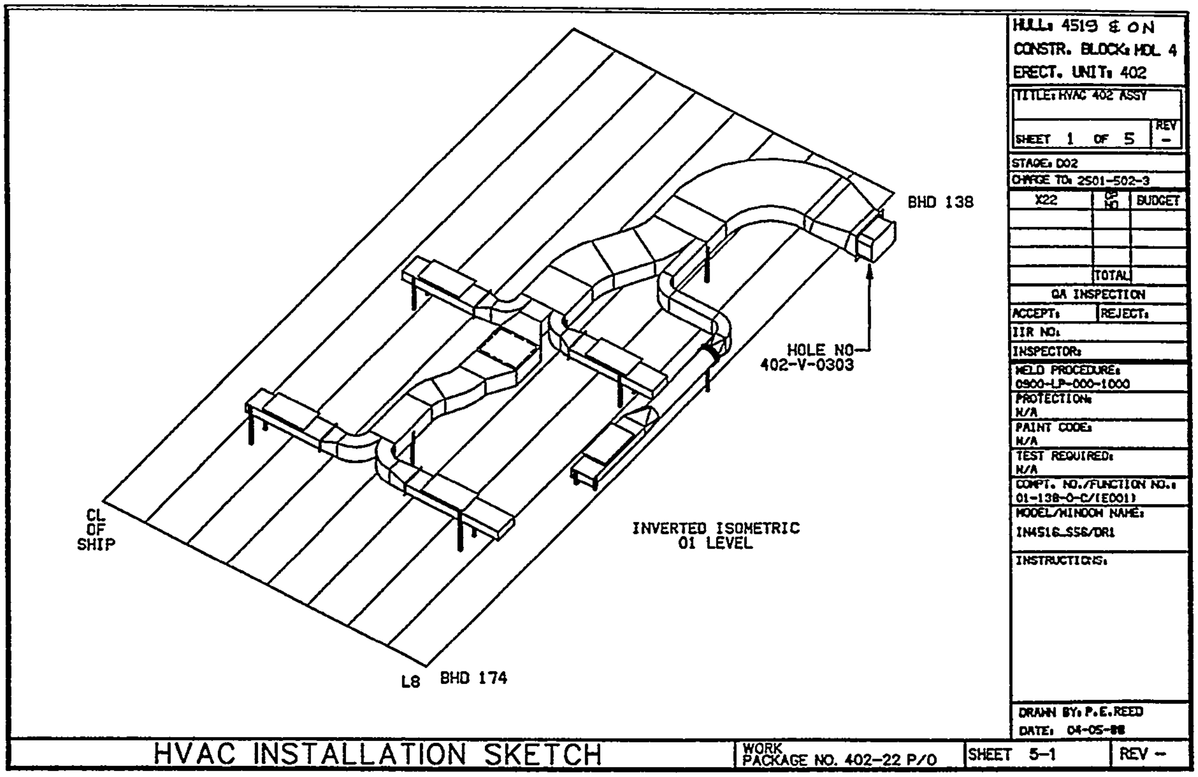


FIGURE 7

DDG 51 DIGITAL DATA TRANSFER

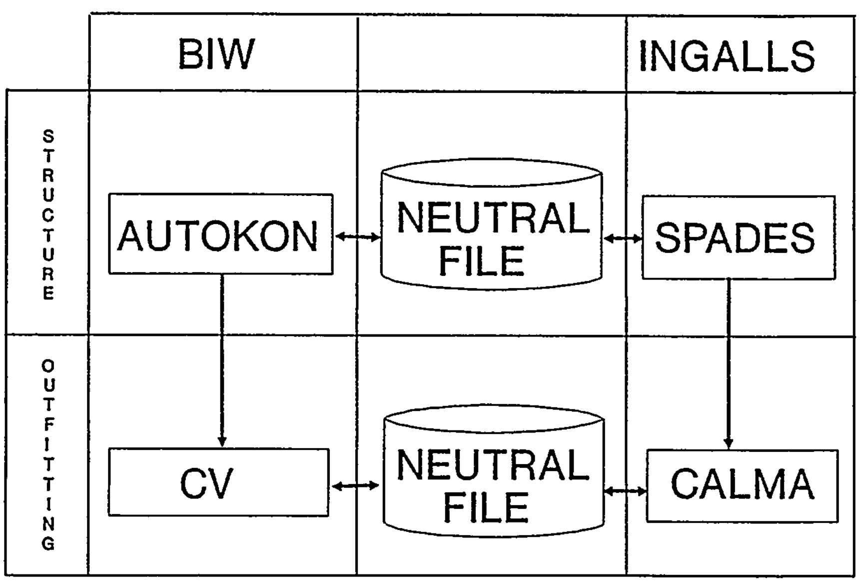
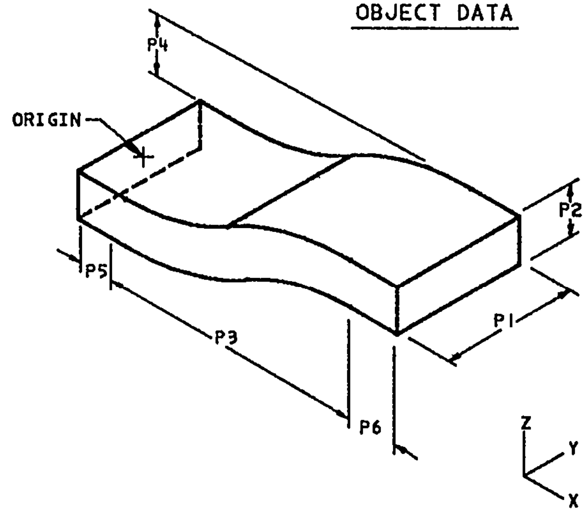


FIGURE 8 - Application Transfer Paths

OVERALL TRANSFER APPROACH (OBJECTS VS. ENTITIES)

PROPOSED APPROACH:



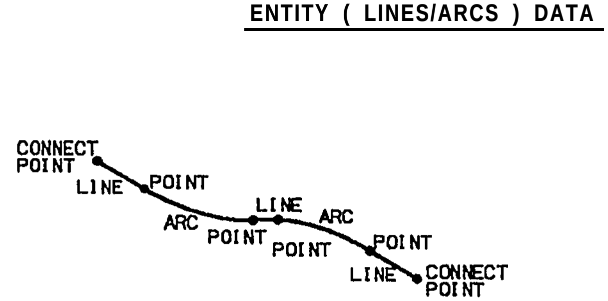
DATA TRANSFERRED:

- ORIGIN
- ORIENTATION
- SHAPE DIMENSIONS

FEATURES :

- RECUCTICN IN TIME/SCHEDULE
- DESIGN TRANSFER CAPABILITY

IGES APPROACH



DATA TRANSFERRED:

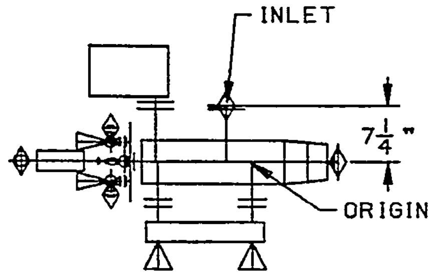
- COMPOSITE CURVE (LINES, ARCS, .POINTS)
  - EACH LINE
    START . END POINTS
  - EACH ARC
    LOCATION
    ORIENTATION
  - EACH POINT
    LOCATION
    DEFINITION OF CROSS-SECTION

FEATURES :

- REQUIRED FOR IGES - BUT NM SUPPORTED
- LIMITED DESIGN TRANSFER CAPABILITIES
- ADEED TIM AND SCHEDULE

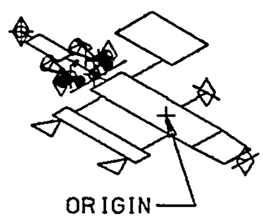
FIGURE 9

FIGURE TOP



PROPERTY
FITTYPE: 80
COMPNAME: "AIRRMVL *E"
STOCK NO: "........."
CONNECTOR (INLET CNODE)
ENDTYPE "FOFF" (INLET/OUTLET CNODE)
INTERNAL (INLINE)

FIGURE ISO (2D)



CLEARANCE ISO

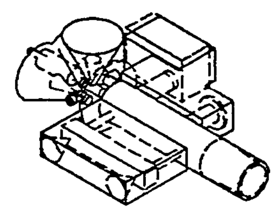
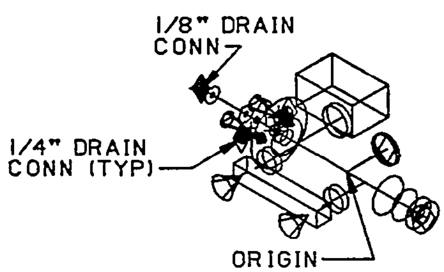
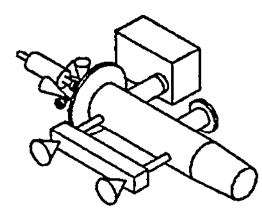


FIGURE ISO (3D)



DETAIL ISO



PREPARED BY: DLB	MODEL SCALE VARIOUS	DESCRIPTION AIR REMOVAL ASSEMBLY	REV E
AUTHORIZED BY: HTB	DATE 4-11-87	LIBRARY SYMBOL FILE NAME P.3.N.ASSY.AIRRMV-01	

FIGURE 10

SH. 1 OF 3

DDT
PROCESS TESTING FLOW CHART

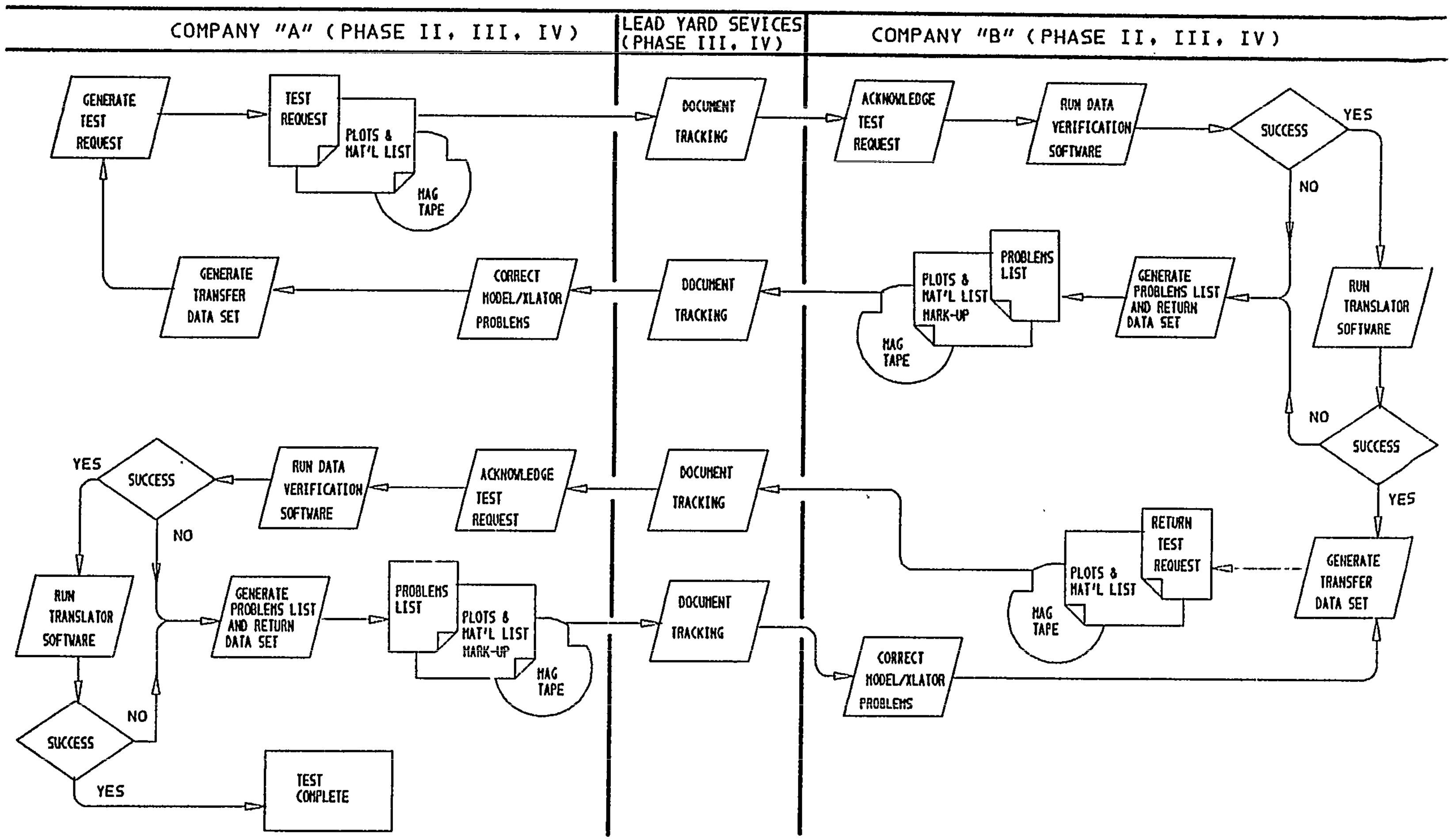
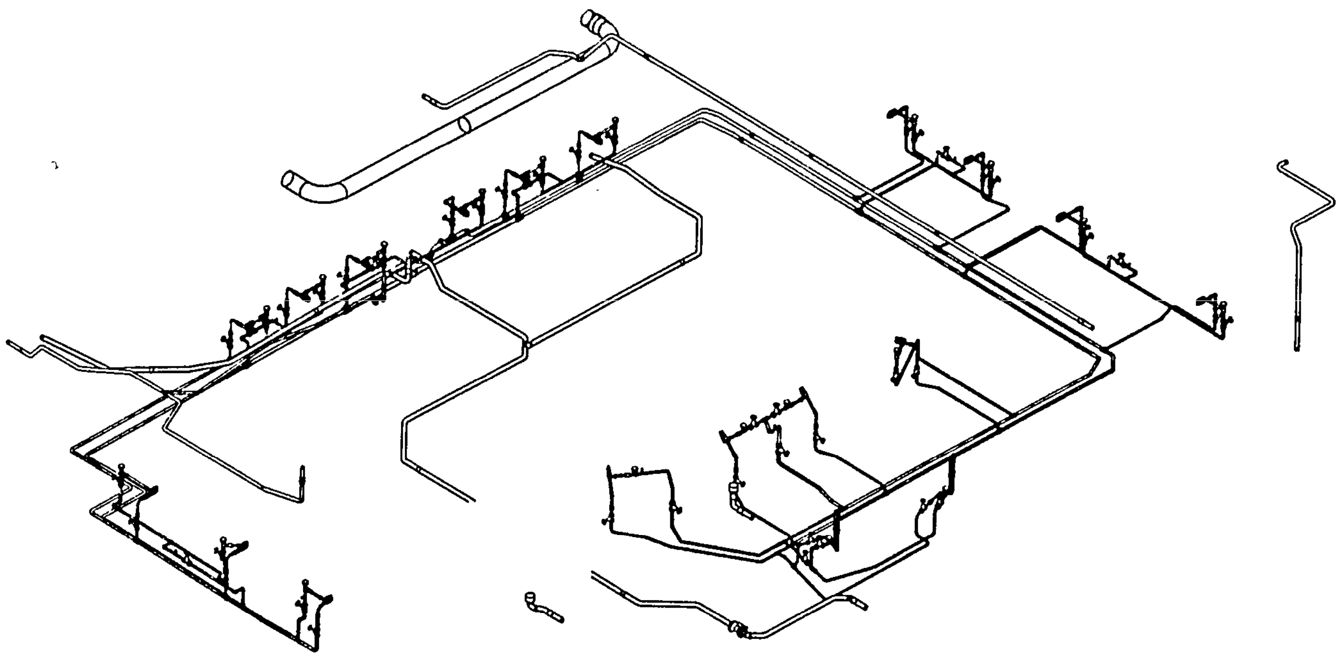


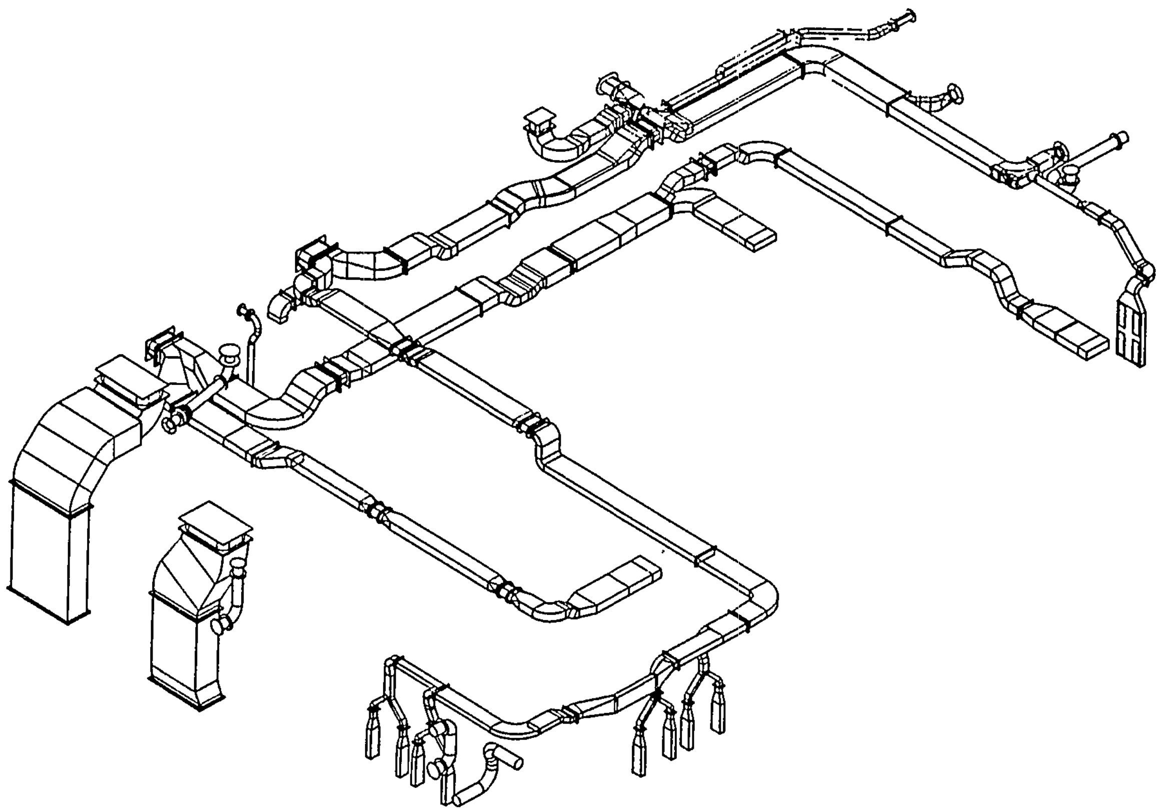
FIGURE 11

5A-I-18



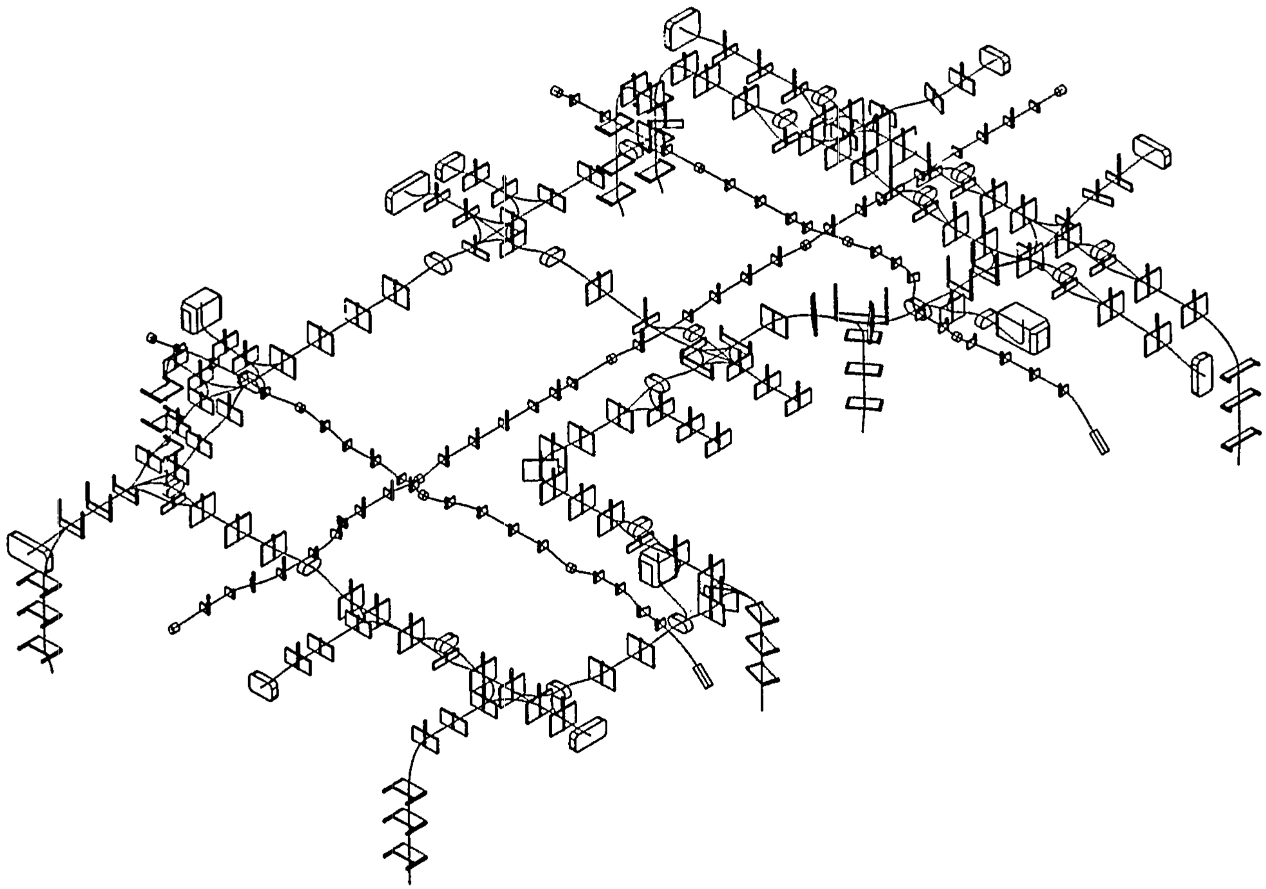
PIPING ZONE 2150 C.I.C

FIGURE 12



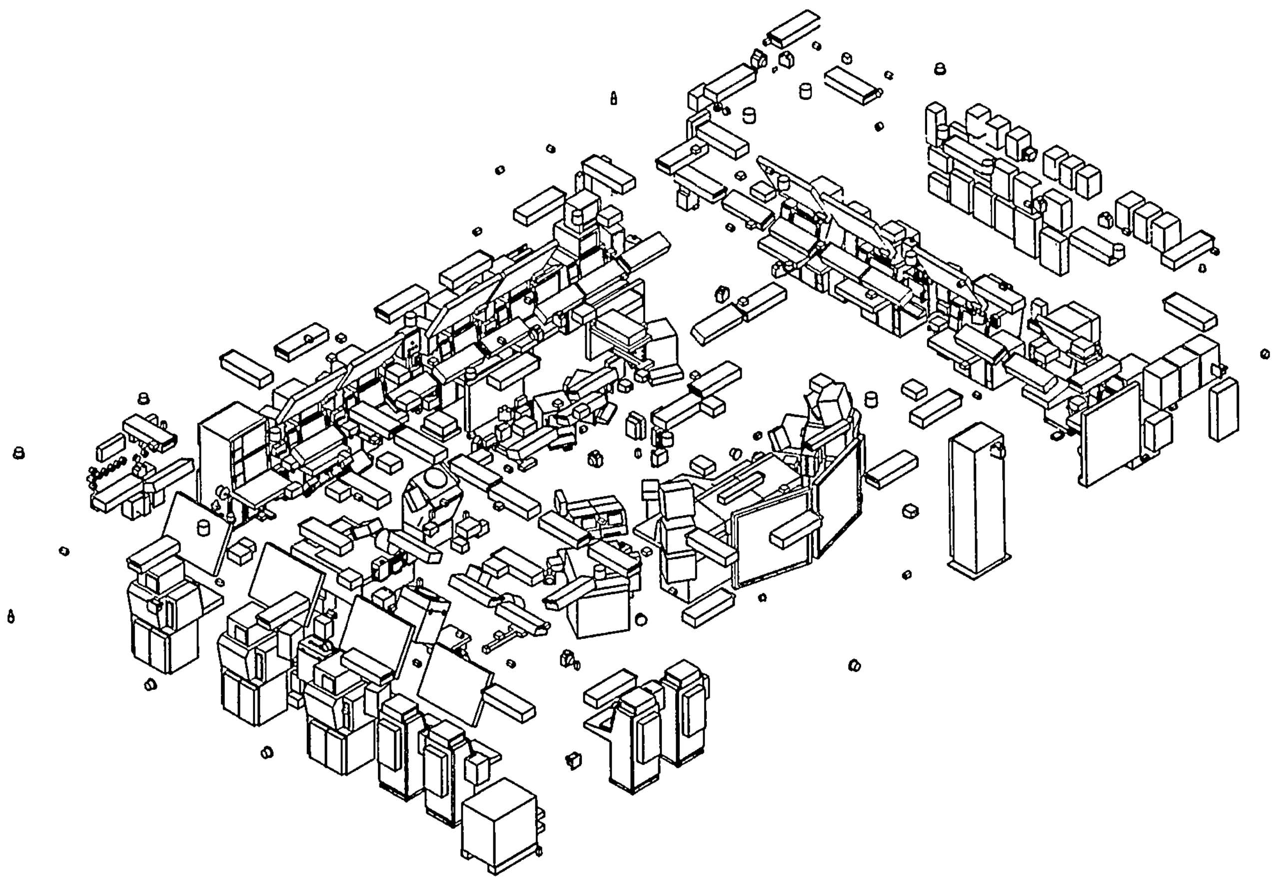
HVAC ZONE 2150

FIGURE 13



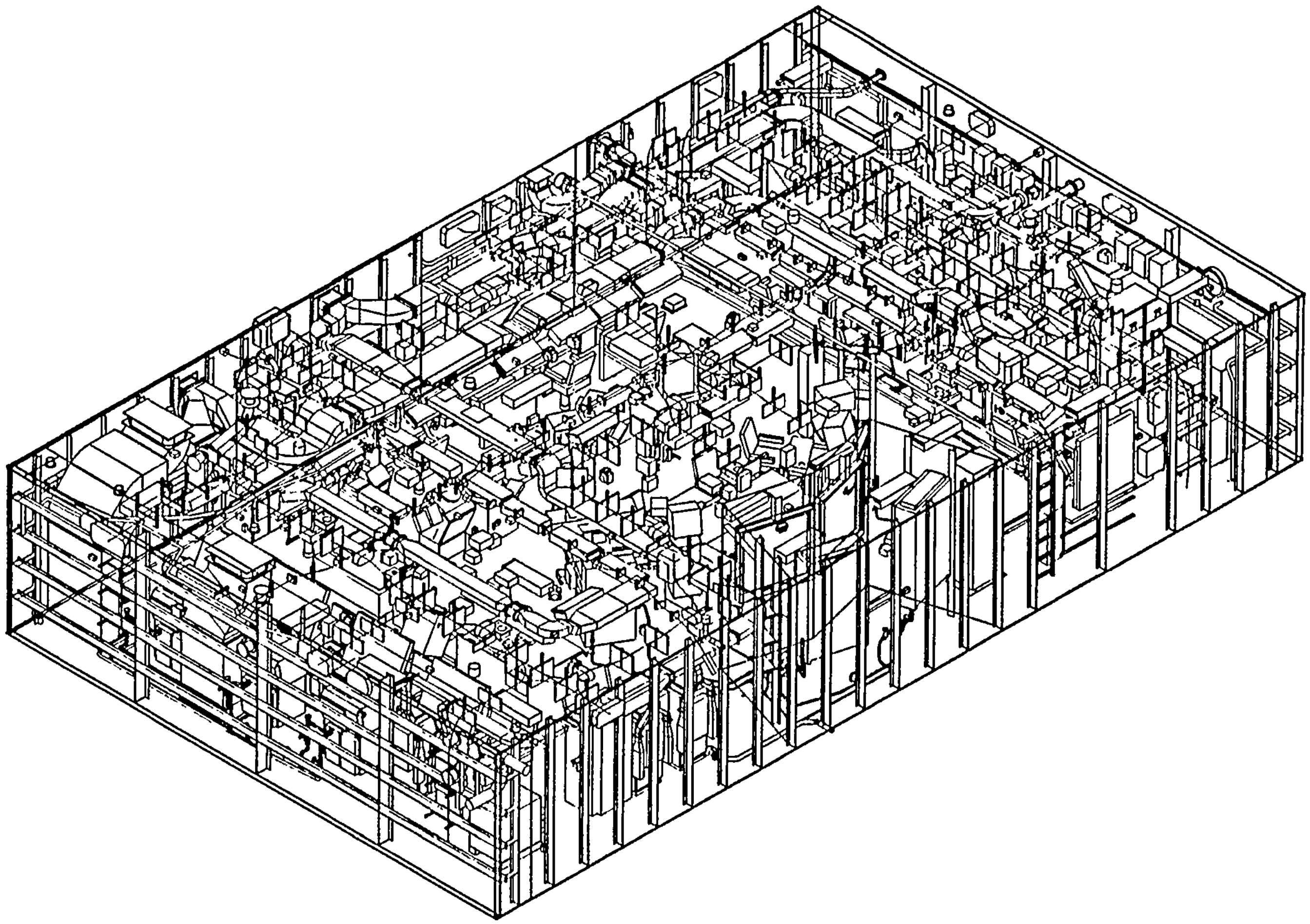
ELECTRICAL WIREWAY ZONE

FIGURE 14A



ELECTRICAL EQUIPMENT ZONE 2150 C.I.C

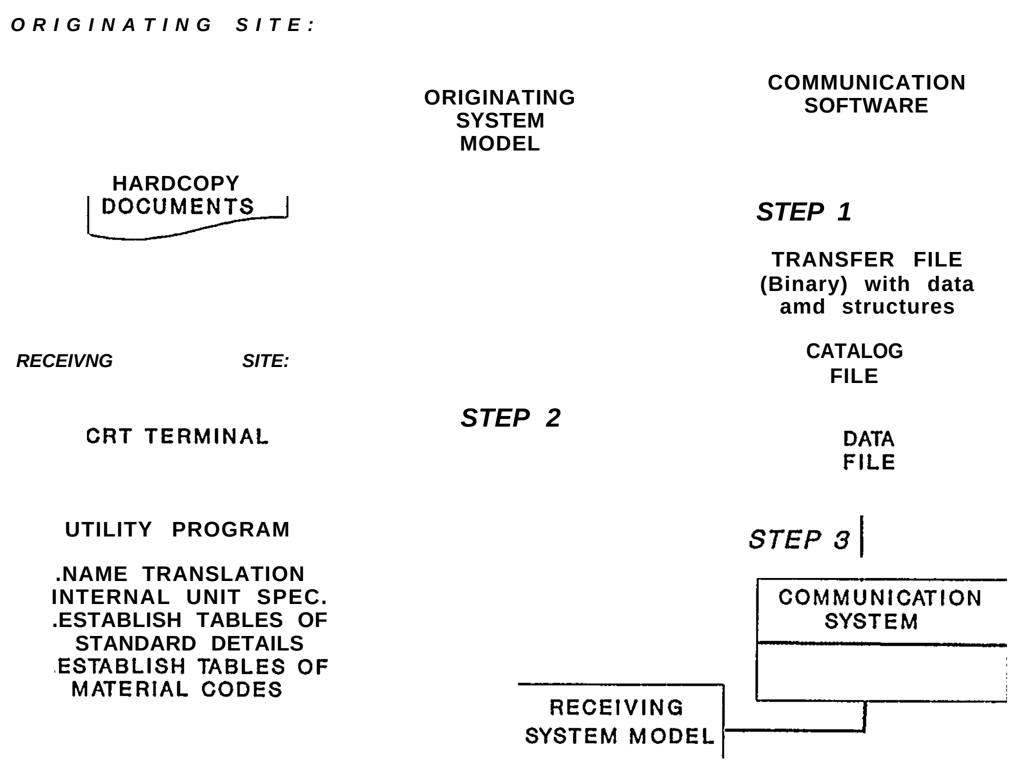
FIGURE 14B



ZONE 2150 C.I.C.
COMPOSITE MODEL ISOMETRIC VIEW

FIGURE 15

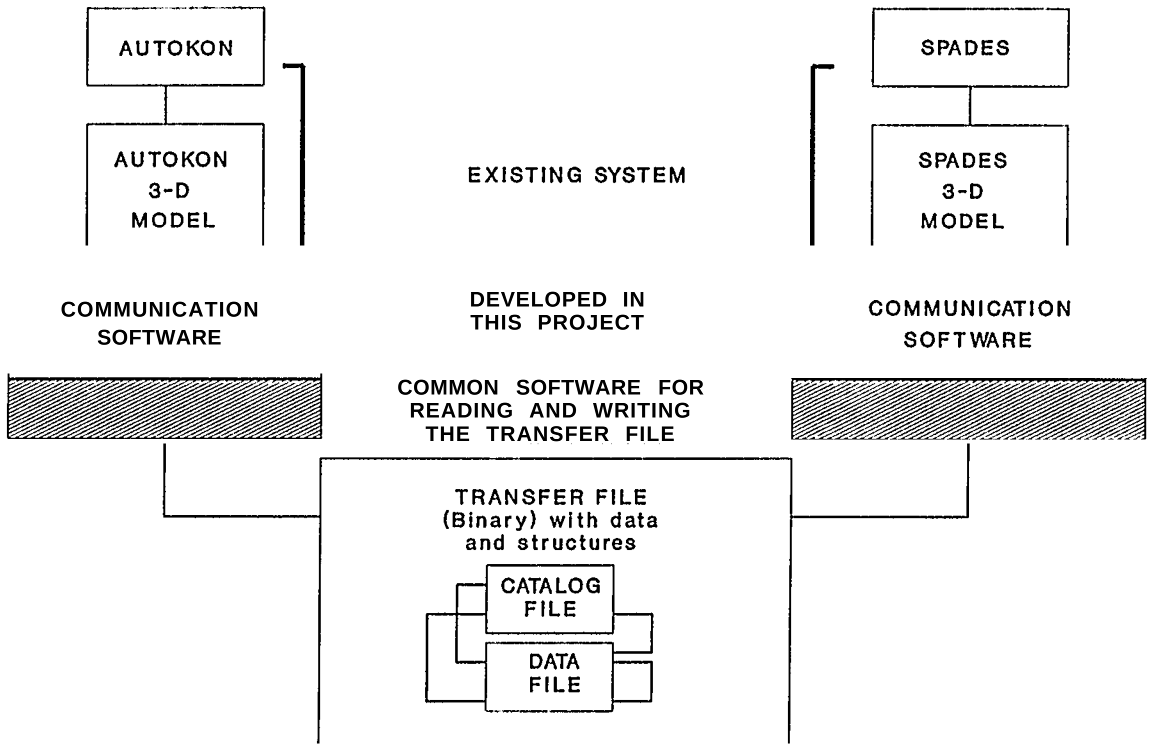
AUTOKON <--> SPADES
COMMUNICATION SYSTEM



Steps of Operation

FIGURE 16

AUTOKON <--> SPADES
MODEL COMMUNICATION SYSTEM



AUTOKON <--> SPADES LINK
FIGURE 17

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24,199O

Computerized Angle Measurement for Inclining Experiments

5A-2

Victor Y. Chen, Member, **Peter K. Weinrich,** Member, JHH, Inc., Portsmouth, VA

ABSTRACT

This paper examines the application of the latest in precision electronic angle measurement instrumentation, combined with portable computer technology, to the measurement of the angles of inclination during inclining experiments. The Computerized Angle Measurement System (CAMS), developed by JJH Inc., will be described as to its configuration and function including the methods used in data acquisition to enhance both its ease of use and accuracy of the results. The software for data acquisition will also be discussed. The CAMS will be compared to traditional pendulums and mechanical tangent inclinometers in the areas of accuracy, cost, and ease of use. CAMS will be shown to be a very accurate, cost effective, and easy to use tool for angle measurement during inclining experiments.

INTRODUCTION

The stability characteristics of a vessel are always a main concern both during its design and throughout its service life. Maintaining adequate stability will ensure the vessel's ability to operate and to meet mission requirements. Inadequate stability will reduce the vessel's operating ability, cargo carrying capacity or could lead to disaster.

While much effort has been put forth in improving the techniques of weight estimating, weight reduction, weight control and weight accounting, during both the design and construction phases, the inclining experiment remains the only satisfactory method for determining the vertical center of gravity of a vessel either at the time of construction or throughout its service life. The inclining experiment provides the basic data for calculating the vessel's weight and centers of gravity in the vertical, longitudinal and transverse directions for use in all evaluations of stability.

During an inclining experiment, certified weights are placed onboard the vessel and shifted to create known transverse moments. The heel angles caused by these moments are accurately measured and their tangents are plotted against the moments to yield a straight line. The vessel's metacentric height (GM) is determined by dividing the slope of the plotted line by the vessel's displacement. A more detailed description of the inclining experiment stability test can be found in References [1] and [2].

Traditionally, the inclining angles have been measured by means of either pendulums or, in the case of many U. S. Navy ship inclinings, mechanical tangent inclinometers. More recently, electrical and electronic devices which display single angle measurements have occasionally been employed. Each of these devices is limited by either the time and expense involved in fabrication and assembly, the need for averaging the inclining angles "by eye", or the lack of a means for permanent data recording.

In order to overcome the limitations of these devices and to take advantage of some of the latest technology in precision electronic angle measurement instrumentation, the Computerized Angle Measurement System (CAMS) was developed.

CONFIGURATION OF THE CAMS

The CAMS consists of a laptop computer, three electronic clinometers, an RS232 serial communications multiplexer and a rechargeable battery. All of the components fit into two brief case size

cases for easy transport. The general configuration of the CAMS is shown in Figure (1).

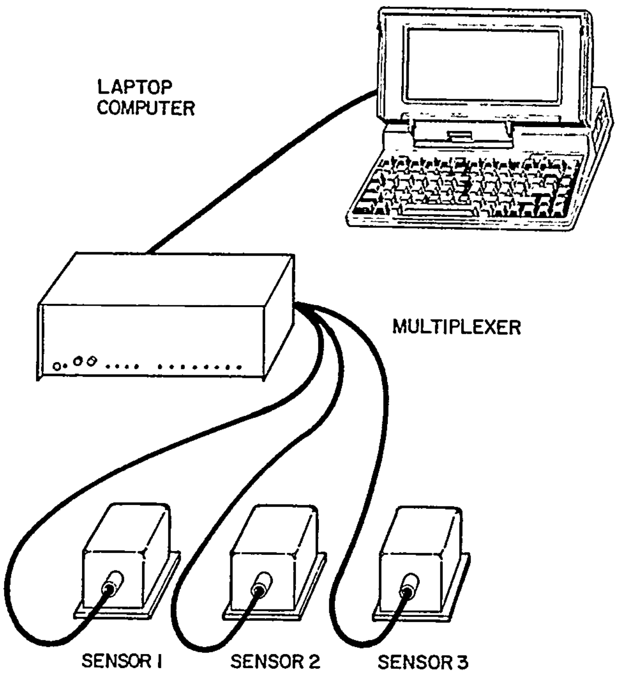


Fig. 1 Configuration of the CAMS

The brain of the system is the driving and controlling software written in BASIC Language and run by the laptop computer. The software is menu driven controlling RS232 serial communications, data acquisition, the saving of data to floppy disk, on-site data review and data printing. Figures (2) and (3) show the main menu and the readings menu. Not shown is the data review menu which has options identical to the readings menu in Figure (3). These three menus provide an overview of the various data acquisition and review options available. Single line prompts are provided for the other main menu options and keyboard inputs such as ship name, weights, and weight movement dimensions. An example of a printed report for a typical inclining is shown in Figure (4).

The system is set-up on a vessel with the laptop computer, the multiplexer and the battery in a weather protected area, usually the ship's bridge, with the clinometers placed as far apart as practical. Each clinometer must be placed on a smooth and solid part of the vessel's structure in locations where they will not be disturbed. The clinometers need not be located on perfectly level as will be explained later.

MAIN MENU

l-INITIALIZE DISK FOR NEW SHIP
2-CALIBRATION
3-TAKE READINGS
4-REVIEW READINGS FROM DISK
5-PRINT DATA TO PRINTER
6-TERMINATE SESSION
ENTER OPTION

Fig. 2 The Main Menu

**************DATA RECORDING MENU**************

l-INITIAL ZERO	10-1ST RECHECK STBD
2-1ST READING STBD	11-2ND RECHECK STBD
3-2ND READING STBD	12-3RD RECHECK STBD
4-3RD READING STBD	13-4TH RECHECK STBD
5-1ST ZERO RECHECK	14-3RD ZERO RECHECK
6-1ST READING PORT	15-1ST RECHECK PORT
7-2ND READING PORT	16-2ND RECHECK PORT
B-3RD READING PORT	17-3RD RECHECK PORT
9-2ND ZERO RECHECK	lB-4TH RECHECK PORT
M-MAIN MENU	

SELECT READING

Fig. 3 The Readings Menu

Each clinometer is housed in an all weather aluminum case, as shown in Figure (5), and is connected to the multiplexer via a 50 foot long cable with an all weather connector, allowing for remote placement. The 50 foot cable length was chosen as it is the maximum allowable length for accurate data transmission without the use of signal repeaters. The multiplexer is a four channel code activated switch which is connected to the RS232 communications port of the laptop computer via a three foot long cable. The multiplexer allows the single computer to switch between the three clinometers through use of software commands. Power for the computer is supplied by either an internal rechargeable battery or a 110 volt AC adapter. The electronic clinometers and the multiplexer are powered by the external rechargeable battery. The capability of operating under battery power was a requirement for all components as a portable system is desired.

******* CAMS INCLINING REPORT *******

SHIP: USS NEVERSAIL

DATE OF INCLINING: 08-31-88

WEIGHTS:

1	1.71 Lt
2	1.70 Lt
3	1.74 Lt
4	1.57 Lt
5	1.30 Lt
6	1.59 Lt

				SENSOR 1		SENSOR 2		SENSOR 3	
OBS	UT #	DIST (ft)	MOMENT (ft-Lt)	ANGLE (deg)	TANGENT (-Stbd)	ANGLE (deg)	TANGENT (-Stbd)	ANGLE (deg)	TANGENT (-Stbd)
1			0	0.00	0.00000	0.00	0.00000	0.00	0.00000
2	1	16.0	27.4	-0.87	-0.01519	-0.90	-0.01571	-0.91	-0.01588
3	1	16.0							
	3	16.0							
	5	16.0	76.0	-2.28	-0.03981	-2.26	-0.03946	-2.27	-0.03964
4	3	16.0							
	5	16.0	48.6	-1.47	-0.02566	-1.47	-0.02566	-1.46	-0.02548
5			0	0.01	0.00017	0.02	0.00035	0.02	0.00035
6	2	16.0	27.2	0.80	0.01396	0.79	0.01379	0.77	0.01344
7	2	16.0							
	4	16.0							
	6	16.0	77.7	2.28	0.03981	2.30	0.04016	2.31	0.04034
	4	16.0							
	6	16.0	50.5	1.48	0.02584	1.50	0.02619	1.52	0.02654

Fig. 4 A Typical Printed Inclining Report

THE CLINOMETER

Within the clinometer case is a microprocessor, a Program Read Only Memory (PROM) computer chip and a sensing unit. The clinometer electronically converts a difference in capacitance into a measurement of angular position. When triggered, the clinometer's microprocessor runs the program (stored in the PROM) reading the difference in capacitance from the sensor and converting this difference into an angle output in the RS232 serial communications format. The sensor and its operation are described as follows:

"The sensor housing consists of two, cast zinc chamber halves with a common capacitor plate sandwiched between. The two sensor halves form electrical ground plates equidistant from the common capacitor plate that isolates them. The capacitor is a copper-plated plastic disc, which has been chemically etched to create two, independent, capacitor plates. A partition in each sensor half electrically isolates the plates, thus forming two chambers in each sensor half. Each chamber is filled with equal amounts (by volume) of a dielectric liquid and an inert gas. Slots at the top and bottom of the partition permit equalization of the fluid level and gas pressure between the chambers.

"When the unit is rotated about its sensitive axis, the liquid and gas within the chambers move with respect to the two common capacitance plates. The liquid has a greater dielectric constant than the gas, so if one common plate is submerged more than the other, it will exhibit higher capacitance. Because of the constant radius (circular) shape, equal amounts of the capacitor plates will be covered/uncovered by the fluid as the sensor rotates. This assures a linear change in capacitance ratio and thus in output signal.

"The clinometer contains integral electronic circuitry to translate the sensor's differential capacitance into a usable output signa1[3]." The shape of the capacitance plate is precisely computer generated and a fluid mixture with an exact dielectric constant, conductivity, and viscosity is used to produce the linearity and resolution shown in Table I. Figure (6) shows the configuration of the sensor housing and capacitor plate.

TABLE I

CLINOMETER SPECIFICATIONS

Linearity	0 to 20 Deg	±0.05 Deg
	20 to 60 Deg	±0.1 Deg
Resolution	±0.001 Deg	
Range	±0 to 60 Deg	

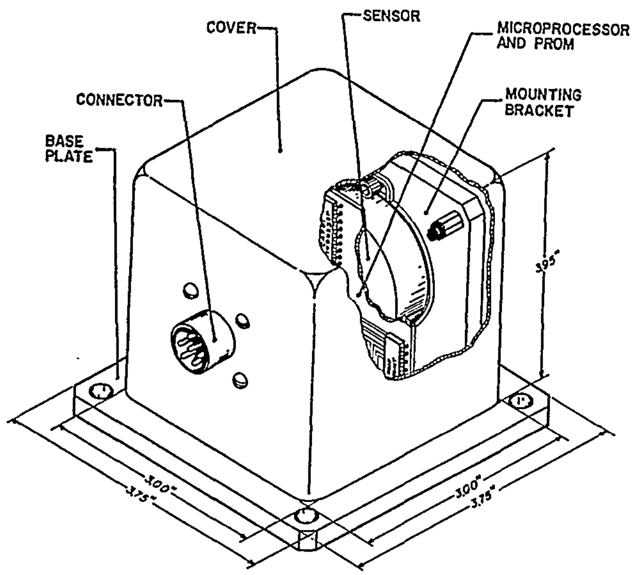


Fig. 5 The Clinometer

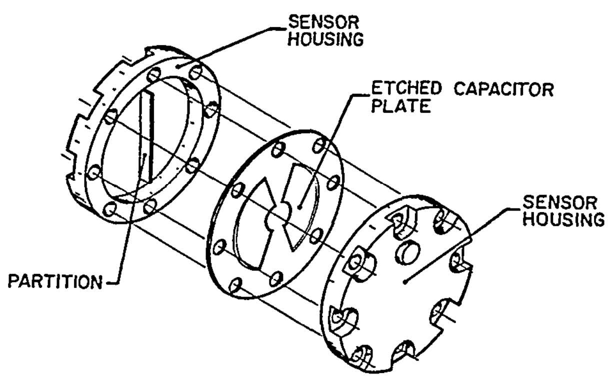


Fig. 6 Exploded View of the Sensor Housing and Capacitor Plate

CALIBRATION

Prior to an inclining experiment the clinometers must be calibrated. This is accomplished by placing the clinometer on a level surface and adjusting an internal zero pot until the clinometer reads zero degrees. Next, a calibration block is placed beneath the clinometer and an internal scale pot is adjusted until the clinometer reads the known angle of the calibration block. The calibration block is then rotated 180 degrees and the clinometer reading is checked to ensure consistency between port and starboard readings. Two calibration blocks have been fabricated, with 2 degree and 5 degree angles, for additional verification of the linearity of the scale adjustment.

Both the *zero* pot and the scale pot are located inside the clinometer's protective case which must be removed for access. The calibration is, therefore, performed in the office rather than on-site. This has proven *to be* quite satisfactory. Once the clinometers have been properly calibrated, no drift has been found in either the zero or scale, even after repeated calibration checks over a period of several months. Even though adjustments may not have to be made, the calibration is checked prior to use on each experiment.

A sub-routine in the computer program is provided for this calibration. With this routine the clinometer to be calibrated is selected and triggered repeatedly. The individual angle readings are displayed on the computer screen allowing for feedback as the zero pot or scale pot are adjusted.

DATA ACQUISITION METHODS

All data acquisition is controlled by the laptop computer running the menu driven computer program. The program provides and controls all channel selection signals to the multiplexer and trigger signals to the clinometers. The program sequences the proper signals to the multiplexer and the clinometers to facilitate the reading of the sensors in as simultaneous a manner as possible. The program also times the trigger signals to the clinometers to ensure triggering of each clinometer's internal sensor reading routine at the optimum frequency.

The sequencing of the program is as follows:

1. Channel 1, for clinometer 1, is selected.
2. Ten individual readings are taken.
3. Checks are made on the individual readings so erroneous data is disregarded. The acceptable data is then averaged.
4. Channel 2, for clinometer 2, is selected.
5. Ten readings are taken, checked and averaged.
6. Channel 3, for clinometer 3, is selected.
7. Ten readings are taken, checked and averaged.
8. Reiterate starting at Step 1.

After five iterations of this loop the five readings are averaged, the inclining angle reading is established and is displayed on the computer screen and saved to the floppy disk.

At the start of an inclining experiment an initial reading is taken at a condition of zero inclining moment. This reading is then used to compute the change in angle, and its tangent, for subsequent readings in the various heeled conditions. Using this method precludes the necessity for adjusting the clinometers to read a zero angle or to be placed on level structures.

COMPARISONS WITH OTHER EQUIPMENT

Pendulums

A typical pendulum arrangement is shown in Figure (7). Three such assemblies must be fabricated and then installed on the vessel at a considerable expenditure of man-hours. It is often difficult to find suitable locations for pendulums which must have a length of 10 feet or more in order to produce the 6 inch minimum deflection at maximum moment required by Reference [2]. This is especially difficult on smaller vessels. Many times the only suitable locations on any vessel are narrow vertical trunks making access for the pendulum reader and providing adequate lighting difficult. Installation and removal of the damping oil is also complicated by tight spaces. Access for accurate measurement of the pendulum length can be hampered by the pendulum being suspended under a hatch. Communication must also be provided between the three pendulum readers and the inclining supervisor.

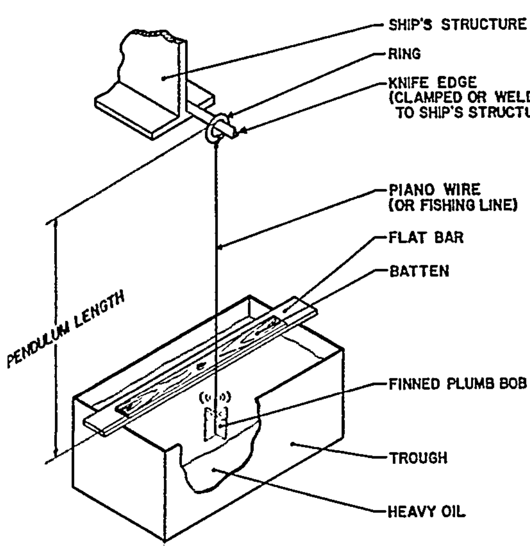


Fig. 7 A Typical Pendulum Assembly

The accuracy of a pendulum reading is largely dependent on the reader's experience and ability to average the pendulum's swing "by eye" and pick the mean of the swing to mark as the reading. There are also errors associated with measurement of the pendulum length and the marked deflection.

The CAMS requires very little time, effort or space for set-up. No vertical trunks are required and the computer can be set up next to the tangent plot table allowing one person to take all of the angle readings and construct the plot of tangents. A minimum of four personnel are required to perform these functions when pendulums are used. Pendulums must be set-up the day before the inclining by several people taking much of the day and inhibiting shin's force in their activities. Set-up on the CAMS requires only about 30 minutes of one person's time on the day of the inclining. The CAMS saves all of the angle readings along with data for weights and their movements while the only permanent record provided by a pendulum are deflection marks on the batten which make up only half of each reading.

Tangent Inclinometers

Figure (8) shows the configuration of a typical mechanical tangent inclinometer. These devices were developed by the U. S. Navy in the 1940's and have been used predominantly for the inclining of U. S. Navy ships. The tangent inclinometer is essentially a short (usually 10 inches long), horizontal pendulum. Three large radius spirit vials are used to establish level for the instrument. Three different radii are provided for coarse and fine adjustment. The unit is placed on a sturdy table or solid structure on the ship and is leveled for the initial zero reading by means of two screw feet. For each heel angle during the inclining, the top plate is re-leveled by using the graduated wheel at the right which turns a threaded rod through the top plate. The left end of the top plate acts as a pivot. The reading is the tangent of the angle and is determined from the position of the

graduated wheel in relation to the vertical scale after re-leveling. An accuracy similar to that of a pendulum is achieved through holding very close tolerances in the machining of the various metal parts.

It is these close tolerances that cause the cost of building one tangent inclinometer to exceed the cost of all of the components of the CAMS together. Three tangent inclinometers would be required for an inclining experiment. The tangent inclinometer also provides no means for direct recording of the angle data like the CAMS and each tangent inclinometer requires an experienced individual reader and communications like those required for pendulums.

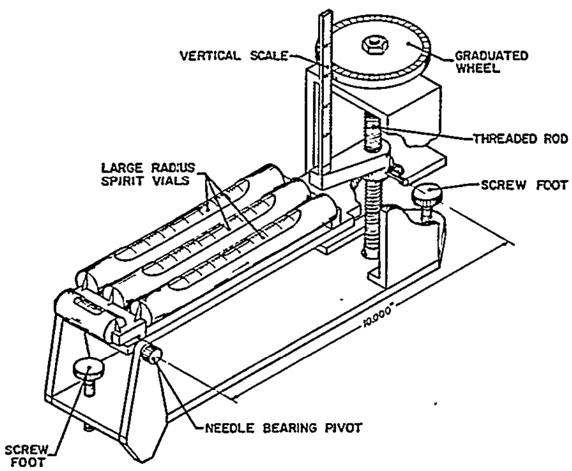


Fig. 8 A Typical Tangent Inclinometer

Other Electrical/Electronic Clinometers

Several electrical and electronic angle sensing devices were investigated during the development of the CAMS. The particular clinometer used in the CAMS was selected because it was the only device found which could provide for computerization of the system, direct saving of numerical values and portability through battery powering, all at a reasonable cost while providing a greater accuracy than any of the other devices considered.

CONCLUSIONS

The CAMS is a very accurate, cost effective, and easy to use angle measurement tool for inclining experiments. It is easier, cleaner and less expensive to install and more portable than pendulums. It also takes less manpower to use and provides for more complete and permanent data recording than either pendulums or tangent inclinometers. The CAMS has been used during inclining experiments on several U. S. Navy ships under the cognizance of the Naval Sea Systems Command (NAVSEA). With CAMS, the inclining experiment has entered the computer age.

REFERENCES

[1] Naval Ships' Technical Manual, Chapter 096, "Weights and Stability," 1977.
[2] United States Coast Guard, Navigation and Vessel Inspection Circular, No. NVC15-81, "Guidelines for Conducting Stability Tests." 1981.
[3] McCarty, Lyle H., Capacitance Difference Reveals Angular Position, Design News, June 1986.

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

An Evaluation of the Fillet Weld Shear Strength of Flux Cored Arc Welding Electrodes

5B-1

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FOREWORD

This report presents the results of a project initiated by SP-7, the Welding R&D Panel of the Ship Production Committee of the Society of Naval Architects and Marine Engineers. The project was financed through a cost sharing contract between the U. S. Maritime Administration and Ingalls Shipbuilding, Incorporated. The principal objective was to develop data on the longitudinal and transverse shear strength of flux cored arc welding filler metals. Consistently higher shear strength properties of flux core over solid wire and conventional electrodes would provide a basis for implementing smaller, more cost effective fillet weld requirements in ship structures.

Flux core filler metals for high yield strength steels (for example, HY-80 and HSLA 80) were qualified for primary hull structures in the early '80's. Some of the early work supported by the National Shipbuilding Research Program contributed to the development and qualification of flux core wire for shipbuilding. The cost savings have been significant. Weld deposition rates of more than 30% increase over solid wire Metal Inert Gas welding have been realized, especially in vertical and overhead welding.

In addition greater use of flux core welding has reduced weld repairs caused by loss of shield gas due to air movement in open areas of the shipyard.

A reduction of fillet weld size would be yet another spin-off benefit of shipyard use of flux cored weld wire.

This project answers any of the questions which have been raised about root penetration and shear strength of fillet welds. The data supports a proposal to revise the U. S. Navy design document to permit smaller fillet welds in structures welded with steels below 80 KSI yield but not the higher strength materials.

When implemented, even the 1/16" reduction in weld sizes indicated by the project results will produce significant reductions in welding costs for both commercial and military ship fabrication.

INTRODUCTION AND OBJECTIVES

In a continuing effort to become more cost effective, U. S. shipyards are implementing a higher percentage of semiautomatic welding processes. Effective shipbuilding fabrication requires the use of efficient, economical welding methods while maintaining high levels of quantity. A large percentage of this welding is performed out of position. The FCAW process is one of the most efficient welding processes for high deposition and quality in out of position fabrication.

FCAW is not a new development. Until recently, process constraints due to electrode characteristics and weldability restricted the applications of FCAW for shipbuilding. However, during the past several years, the filler material manufacturing industry has performed much research and development work that has resulted in flux cored electrodes with excellent strength and toughness which can be welded in all positions. Improvement in the manufacturing process controls and raw material selection ensures consistent high quality which provide the necessary mechanical properties to expand FCAW applications to include higher strength steels such as HY-80[4] and HSLA-80[5].

In ship design, shear strength is emphasized when determining fillet weld size requirements. The joint efficiency is based upon the load carrying capacity of the weaker member and the shear strength of the filler metal. The current design document, MIL-STD-1628, does not include the fillet weld shear strength values for FCAW electrodes. Presently, the comparable SMAW electrode values are used for design purposes.

This project was undertaken because of the large amount of fillet welds in a typical ship design. It is common for 90% of the joints to be fillet welds for structural connections. This represents several miles of weld length for each ship.

Two FCAW electrodes, MIL-71T1-HY and MIL-101-TC/TM, were evaluated in this series of tests. Their respective chemistries are noted in Table I. These electrodes typically have higher tensile strength values and have superior penetration capabilities than their respective SMAW equivalents, namely the MIL-7018-M[6] and MIL-10018-M1[7] covered electrodes. The criteria from MIL-STD-1628 does not consider the possible effects that these characteristics may have on the joints shear mechanics which may result in higher fillet weld shear values. The effect may be significant enough to warrant reduction of required fillet weld sizes in the design stage of ships with no reduction in structural strength (See Figure 1). Primary benefits to be expected from reduction in fillet weld size requirements are significant weight reductions and reduction in production costs in both manhours and materials.

Shear specimen preparation, testing, and evaluation are dealt with in depth in the succeeding text. All laboratory efforts were conducted in strict accordance with ANSI/AWS B4.0-85[8] in an attempt to produce repeatable data.

Table I. FCAW Electrode Chemistries

	MIL-71T1-HY	MIL-101-TC/TM
C	0.12	0.10
Mn	0.50-1.75	0.50-1.50
Si	0.90	0.60
Ph	0.030	0.020
S	0.030	0.017
Ni	0.50	1.30-3.75
Cr	0.20	0.20
Mo	0.30	0.50
V	0.05	0.05
Cu	0.20	0.06

LABORATORY EFFORT

Longitudinal and transverse shear specimens were prepared with 0.052" (1.3mm) diameter FCAW electrodes. The electrodes were provided by various manufacturers and tested with both a 75% argon/25% CO_2 shielding gas mixture and a shielding of straight welding grade CO_2. Specimens were prepared from HY-80, HSLA-80, and AH-36[9] steels. Using identical weld parameters (235 amps, 25 volts, 15 ipm) and an automatic tracking system, lab technicians prepared 1/4" (6.4mm) single pass fillets and 3/8" (9.5mm) three pass fillets. A total of

Figure 1. USS WASP (LHD 1), Multipurpose Amphibious Ship

96 tests were conducted with the purpose of developing a broad data base.

Each specimen was positioned in a tensile machine where the load was applied parallel to the axis of the specimen (See Figures 2 and 3). Records were kept documenting the maximum force needed to produce each shear failure, actual shear lengths, fillet sizes, throat dimensions and estimated angle of shear.

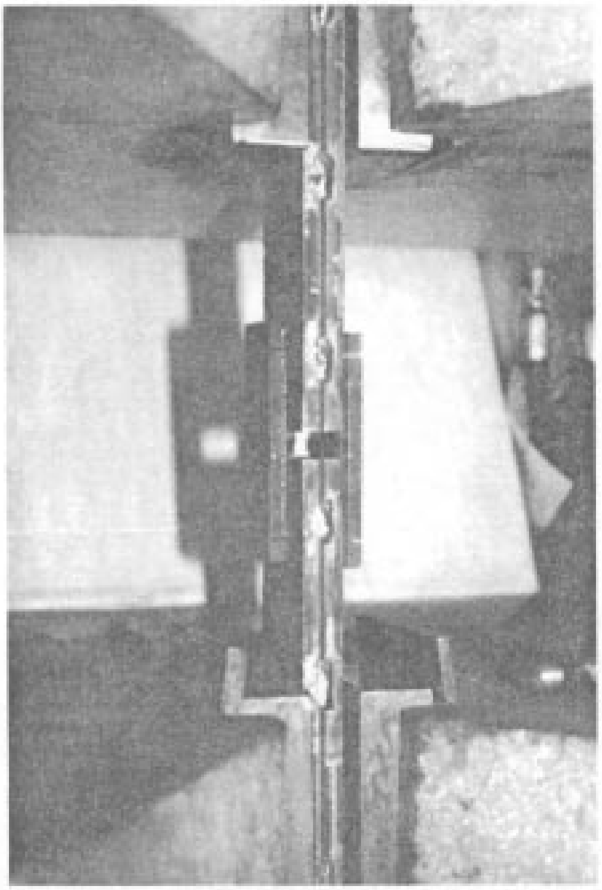


Figure 2. Longitudinal Shear Specimen

After measuring the fillet sizes, the theoretical throat was calculated and used to determine the specimen's shear strength as specified in ANSI/AWS B4.0-85 (See Figure 4).

To conclude all laboratory efforts, six longitudinal and six transverse specimens were the subject of a metallographic analysis. Shown photographs (Figures 9 through 20) clearly reveal arc penetrating characteristics and the angle of shear at which failure occurred.

RESULTS

Results of the longitudinal and transverse shear tests are exhibited in Tables II through VII. The data is segregated into filler wire, shield gases, and fillet weld sizes. Tables VIII and IX list the averages for each set of values.

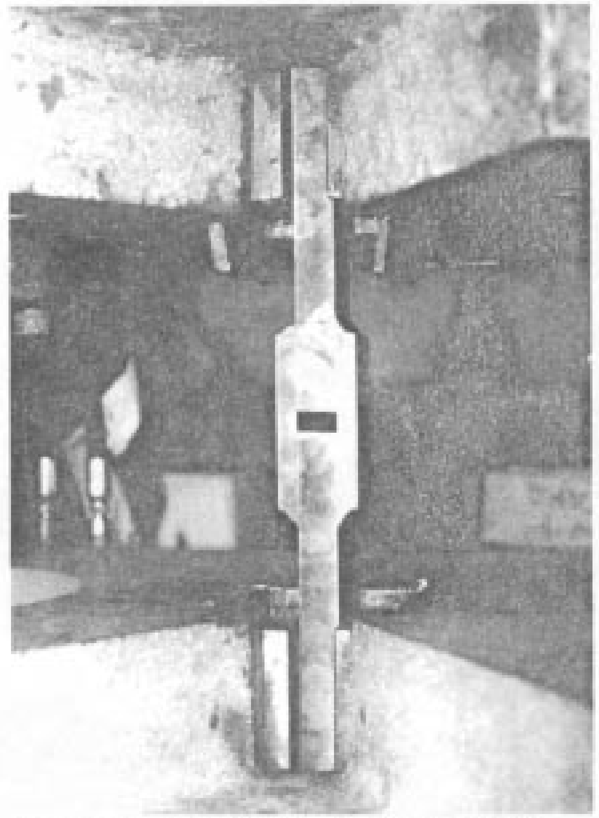


Figure 3. Transverse Shear Specimen

Following the destructive tests, each specimen was examined and its angle of shear estimated. The tables contain these estimations and Figures 5 and 6 exhibit the observed 45° and 22.5° shear angles.

To evaluate the weld penetration, a macrographic analysis was conducted on select transverse and longitudinal specimens. Figures 7 and 8 are drawings showing the cross-sectional areas relevant to the metallography in Figures 9 through 20.

The succeeding tables contain data noted and developed during the fabrication and destructive evaluation of shear specimens. The following is a column by column explanation of the information included in the tables:

1. Specimen number as designated during lab testing.

2. Specimens were tested using 75% Argon/25% CO_2 mixed gas shielding and a straight CO_2 shielding.

3. Electrodes were evaluated from two different wire manufacturers.

4. Targeted fillet size during fabrication of shear specimens.

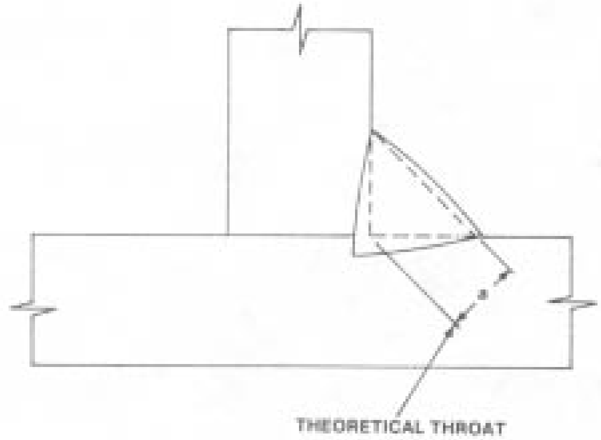
5. Actual measured fillet sizes.

6. Calculated throat assuming a 45° shear angle as required by ANSI/AWS B4.0-85.

7. Shear load in pounds per linear inch as determined by tensile testing.

8. Shear strength in PSI assuming a 45° shear angle as required by ANSI/AWS B 4.0-85.

9. Actual shear angle visually determined following destructive tests.



$$s = \frac{p}{l \times a}$$

WHERE:

p Load
l = Total Length of Fillet Weld Sheared
a = Theoretical Throat Dimension
s = Shear Strength of Weld

Figure 4. Shear Strength Calculation (ANSI/AWS B-4.0-85)

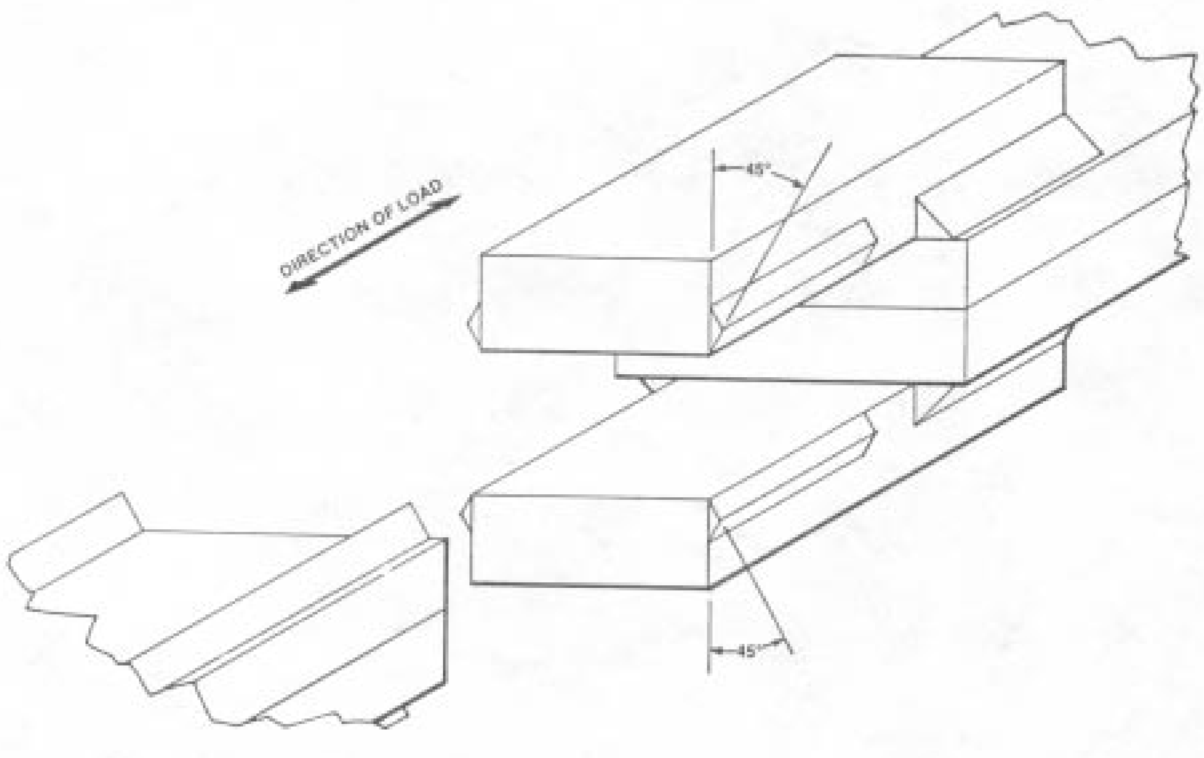


Figure 5. Typical Longitudinal Shear Failure Angle

Table II. Longitudinal Shear Data Base Material--AH-36, Filler Material--71TJ-HY

SPECIMEN	SHIELD GAS	WIRE MFG	FILLET SIZE	ACTUAL FILLET SIZE	THEORET THROAT	SHEAR LOAD	SHEAR STRENGTH	SHEAR ANGLE
1A	75/25	A	1/4"	.270	.191	11,916	62,391	45°
2A	75/25	A	1/4"	.250	.177	12,436	70,260	45°
3A	75/25	B	1/4"	.265	.187	11,046	59,070	45°
4A	75/25	B	1/4"	.250	.177	11,571	65,373	45°
5A	CO_2	A	1/4"	.265	.187	11,951	63,909	45°
6A	CO_2	A	1/4"	.250	.177	12,018	67,896	45°
7A	CO_2	B	1/4"	.250	.177	11,864	67,030	45°
8A	CO_2	B	1/4"	.250	.177	12,137	68,569	45°
9A	75/25	A	3/8"	.375	.265	18,476	69,721	45°
10A	75/25	A	3/8"	.360	.256	16,498	64,820	45°
11A	75/25	B	3/8"	.350	.250	18,407	74,389	45°
12A	75/25	B	3/8"	.375	.265	19,950	75,279	45°
13A	CO_2	A	3/8"	.375	.265	17,517	66,102	45°
14A	CO_2	A	3/8"	.365	.258	18,718	72,547	45°
15A	CO_2	B	3/8"	.360	.255	18,650	73,275	45°
16A	CO_2	B	3/8"	.335	.237	17,664	74,580	45°

Table III. Longitudinal Shear Data Base Material--HY-80, Filler Material--101TC/TM

SPECIMEN	SHIELD GAS	WIRE MFG	FILLET SIZE	ACTUAL FILLET SIZE	THEORET THROAT	SHEAR LOAD	SHEAR STRENGTH	SHEAR ANGLE
17A	75/25	A	1/4"	.270	.191	12,438	65,119	45°
18A	75/25	A	1/4"	.260	.184	12,007	65,255	45°
19A	75/25	B	1/4"	.260	.184	11,953	64,961	45°
20A	75/25	B	1/4"	.275	.194	12,093	62,201	45°
21A	CO_2	A	1/4"	.250	.177	13,065	73,815	45°
22A	CO_2	A	1/4"	.260	.184	12,936	70,305	45°
23A	VOID							
24A	CO_2	B	1/4"	.250	.177	13,443	75,950	45°
25A	75/25	A	3/8"	.350	.250	19,430	78,521	45°
26A	75/25	A	3/8"	.360	.255	19,240	75,272	45°
27A	75/25	B	3/8"	.365	.260	20,154	78,101	45°
28A	75/25	B	3/8"	.370	.262	19,577	74,720	45°
29A	CO_2	A	3/8"	.345	.244	21,127	86,615	45°
30A	CO_2	A	3/8"	.355	.250	20,226	80,585	45°
31A	CO_2	B	3/8"	.340	.240	20,865	86,793	45°
32A	CO_2	B	3/8"	.370	.262	20,291	77,447	45°

Table IV. Longitudinal Shear Data Base Material--HSLA-80, Filler Material--101TC/TM

SPECIMEN	SHIELD GAS	WIRE MFG	FILLET SIZE	ACTUAL FILLET SIZE	THEORET THROAT	SHEAR LOAD	SHEAR STRENGTH	SHEAR ANGLE
33A	75/25	A	1/4"	.250	.177	13,905	78,560	45°
34A	75/25	A	1/4"	.225	.160	12,730	80,022	45°
35A	75/25	B	1/4"	.250	.177	11,952	67,525	45°
36A	75/25	B	1/4"	.250	.177	11,597	65,518	45°
37A	CO_2	A	1/4"	.265	.187	15,160	80,911	45°
38A	CO_2	A	1/4"	.250	.177	14,808	83,663	45°
39A	CO_2	B	1/4"	.245	.173	11,622	67,178	45°
40A	CO_2	B	1/4"	.245	.173	11,885	68,697	45°
41A	75/25	A	3/8"	.360	.255	19,404	76,245	45°
42A	75/25	A	3/8"	.375	.265	18,933	71,445	45°
43A	75/25	B	3/8"	.375	.265	19,631	74,079	45°
44A	75/25	B	3/8"	.355	.250	19,371	77,182	45°
45A	CO_2	A	3/8"	.370	.262	19,421	74,238	45°
46A	CO_2	A	3/8"	.400	.283	18,772	66,332	45°
47A	CO_2	B	3/8"	.350	.248	19,123	77,108	45°
48A	CO_2	B	3/8	.260	.255	19,641	77,025	45°

Table V. Transverse Shear Data Base Material--AH-36, Filler Material--71T1-HY

SPECIMEN	SHIELD GAS	WIRE MFG	FILLET SIZE	ACTUAL FILLET SIZE	45° THEORET THROAT	SHEAR LOAD	45° SHEAR STRENGTH	SHEAR ANGLE	22.5° THEORET THROAT	22.5° SHEAR STRENGTH	SHEAR STRENGTH DIFFERENCE
1B	75/25	A	1/4"	.270	.191	18,875	98,874	20-25°	.207	91,184	8.4%
2B	75/25	A	1/4"	.280	.198	20,000	101,010	20-25°	.214	93,340	8.2%
3B	75/25	B	1/4"	.320	.230	21,333	94,295	20-25°	.245	87,127	8.2%
4B	75/25	B	1/4"	.270	.191	17,750	92,985	20-25°	.207	85,919	8.2%
5B	CO_2	A	1/4"	.280	.198	19,211	97,042	20-25°	.214	89,771	8.1%
6B	CO_2	A	1/4"	.230	.163	17,105	105,192	20-25°	.176	97,196	8.2%
7B	CO_2	B	1/4"	.270	.191	21,750	113,940	20-25°	.207	105,072	8.4%
8B	CO_2	B	1/4"	.275	.194	22,308	114,737	20-25°	.210	106,229	8.0%
9B	75/25	A	3/8"	.365	.258	24,750	95,910	20-25°	.279	88,710	8.1%
10B	75/25	A	3/8"	.350	.248	28,169	113,837	15-20°	.268	105,108	8.3%
11B	75/25	B	3/8"	.400	.283	30,000	106,082	15-20°	.306	98,039	8.2%
12B	75/25	B	3/8"	.375	.265	26,667	100,581	7-12°	.287	92,916	8.3%
13B	CO_2	A	3/8"	.350	.248	25,946	104,853	7-12°	.268	96,813	8.3%
14B	CO_2	A	3/8"	.400	.283	27,692	97,852	20-25°	.306	90,497	8.1%
15B	CO_2	B	3/8"	.375	.265	29,305	110,535	10-15°	.287	102,108	8.3%
16B	CO_2	B	3/8"	.360	.255	28,378	111,498	10-15°	.276	102,819	8.4%

10. Calculated throat assuming a 22.5° shear angle (transverse only).

11. Shear strength in PSI assuming a 22.5° shear angle (transverse only).

12. Shear strength difference between assumed shear angles of 45° and 22.5° (transverse only).

DISCUSSION

MIL-STD-1628 employs an array of efficiency charts to determine fillet weld sizes. Each chart is based on a computation factor, which is a function of the base material strength and weld metal shear strength. The computation factor is calculated using the following formula:

$$C_F = \frac{R_1}{1.414\,R_2}$$

R_1 = Ultimate Tensile Strength of Weaker Member (psi)

R_2 = Shear Strength of Weld Metal (psi)

Table VI. Transverse Shear Data Base Material--HY-80, Filler Material--101TC/TM

SPECIMEN	SHIELD GAS	WIRE MFG	FILLET SIZE	ACTUAL FILLET SIZE	45° THEORET THROAT	SHEAR LOAD	45° SHEAR STRENGTH	SHEAR ANGLE	22.5° THEORET THROAT	22.5° SHEAR STRENGTH	SHEAR STRENGTH DIFFERENCE
17B	75/25	A	1/4"	.270	.191	19,750	103,463	20-25°	.207	95,411	8.4%
18B	75/25	A	1/4"	.250	.177	20,000	113,154	20-25°	.192	104,167	8.6%
19B	75/25	B	1/4"	.330	.233	20,811	89,198	20-25°	.252	82,583	8.0%
20B	75/25	B	1/4"	.290	.205	21,918	106,900	20-25°	.222	98,730	8.3%
21B	CO_2	A	1/4"	.275	.194	20,811	107,038	20-25°	.210	99,100	8.0%
22B	CO_2	A	1/4"	.250	.177	22,632	128,043	20-25°	.192	117,875	8.6%
23B	CO_2	B	1/4"	.305	.216	21,538	99,883	20-25°	.234	92,043	8.5%
24B	CO_2	B	1/4"	.285	.202	22,676	112,539	20-25°	.219	103,543	8.7%
25B	75/25	A	3/8"	.400	.283	31,282	110,537	40-45°	.306	102,229	8.1%
26B	75/25	A	3/8"	.395	.279	30,650	109,750	20-25°	.302	101,490	8.1%
27B	75/25	B	3/8"	.355	.250	27,317	108,840	5-10°	.271	100,801	8.0%
28B	75/25	B	3/8"	.395	.279	33,514	120,006	5-10°	.302	110,974	8.1%
29B	CO_2	A	3/8"	.395	.279	32,368	115,906	20-25°	.302	107,179	8.1%
30B	CO_2	A	3/8"	.400	.283	30,000	106,082	20-25°	.306	98,039	8.2%
31B	CO_2	B	3/8"	.400	.283	28,158	99,568	5-10°	.306	92,120	8.1%
32B	CO_2	B	3/8"	.390	.276	29,872	108,337	15-20°	.299	99,906	8.4%

Table VII. Transverse Shear Data Base Material--HSLA-80, Filler Material--101TC/TM

SPECIMEN	SHIELD GAS	WIRE MFG	FILLET SIZE	ACTUAL FILLET SIZE	45° THEORET THROAT	SHEAR LOAD	45° SHEAR STRENGTH	SHEAR ANGLE	22.5° THEORET THROAT	22.5° SHEAR STRENGTH	SHEAR STRENGTH DIFFERENCE
33B	75/25	A	1/4"	.260	.184	18,750	102,002	20-25°	.199	94,221	8.3%
34B	75/25	A	1/4"	.275	.194	20,000	102,867	20-25°	.210	95,238	8.0%
35B	75/25	B	1/4"	.280	.198	18,519	93,547	20-25°	.214	86,537	8.1%
36B	75/25	B	1/4"	.255	.180	19,512	108,230	20-25°	.195	100,062	8.2%
37B	CO_2	A	1/4"	.275	.194	19,351	99,528	20-25°	.210	92,148	8.0%
38B	CO_2	A	1/4"	.255	.180	17,037	94,500	26-30°	.195	87,369	8.2%
39B	CO_2	B	1/4"	.275	.194	18,250	93,866	26-30°	.210	86,905	8.0%
40B	CO_2	B	1/4"	.265	.187	18,974	101,275	20-25°	.202	93,931	7.8%
41B	75/25	A	3/8"	.410	.290	27,000	93,145	20-25°	.314	85,987	8.3%
42B	75/25	A	3/8"	.405	.286	26,000	90,803	20-25°	.310	83,871	8.3%
43B	75/25	B	3/8"	.380	.269	27,000	100,499	20-25°	.291	92,784	8.3%
44B	75/25	B	3/8"	.400	.283	28,684	101,358	20-25°	.306	93,739	8.1%
45B	CO_2	A	3/8"	.385	.272	26,750	98,275	20-25°	.294	90,986	8.0%
46B	CO_2	A	3/8"	.400	.283	26,750	94,590	20-25°	.306	87,418	8.2%
47B	CO_2	B	3/8"	.400	.283	26,154	92,482	20-25°	.306	85,471	8.2%
48B	CO_2	B	3/8"	.375	.265	24,500	92,409	5-10°	.287	85,366	8.3%

Table VIII. Average Longitudinal Shear Strength Valves

BASE MATERIAL	SHIELD GAS	(PSI) SHEAR STRENGTH
AH36 (MIL-71T1-HY)	CO_2	69,239
	75 Ar/25 CO_2	67,663
	Average	68,451
HY-80 (MIL-101TC/TM)	CO_2	78,787
	75 Ar/25 CO_2	70,519
	Average	74,378
HSLA-80 (MIL-101TC/TM)	CO_2	74,394
	75 Ar/25 CO_2	73,822
	Average	74,108

Table IX. Average Transverse Shear Strength Values

MATERIAL BASE	SHEAR ANGEL	SHIELD GAS	(PSI) SHEAR STRENGTH
AH36	45°	CO_2	106,956
(MIL-71T1-HY)		75 Ar/ 25 CO_2	100,447
		Average	103,701
AH36	22.5°	CO_2	98,813
(MIL-71T1-HY)		75 Ar/ 25 CO_2	92,793
		Average	95,803
HY-80	45°	CO_2	109.675
(MIL-101TC/TM)		75 Ar/ 25 CO_2	107,731
		Average	108,702
HY-80	22.5°	CO_2	101,226
(MIL-101TC/TM)		75 Ar/ 25 CO_2	99,548
		Average	100,387
HSLA-80	45°	CO_2	95,866
(MIL-101TC/TM		75 Ar/ 25 CO_2	99.056
		Average	97,461
HSLA-80	22.5°	CO_2	88,699
MIL-101TC/TM)		75 Ar/ 25 CO_2	91,555
		Average	90,127

MIL-STD-1628 specifies a longitudinal shear strength of 59 KSI (407 MPa) for MIL-70XX covered electrodes. The values for the MIL-71T1-HY electrodes, as shown in Table VIII, average 68 KSI (476 MPa). Comparing the computation factors calculated with an R_1 (High Tensile Steel) value of 75 KSI (517 MPa), the SMAW and FCAW values are .90 and .75 respectively. Figures 21 and 22 are MIL-STD-1628 efficiency charts for these computation factors. A definite reduction in fillet weld size can be appreciated with the implementation of the MIL-71T1-HY data.

MIL-STD-1628 specifies a longitudinal shear strength of 87 KSI (600 MPa) for the MIL-11018-M[10] covered electrode and 83 KSI (572 MPa) for the MIL-100S-1[11] bare electrode. However, as a result of recent shear testing[12] a potential revision to MIL-STD-1628 is proposed to reduce the MIL-11018-M covered electrode shear criteria to 79 KSI (545 MPa) and set the value for MIL-10018-M1 at 72 KSI (496 MPa). The values for the MIL-101-TC/TM electrodes as shown in Table VIII averaged above 74 KSI (510 MPa) providing strong support for a revision.

Another topic of discussion that arose during laboratory work concerned observations of the shear fractures that followed each test. A Vernier Caliper was used to measure the specimen's leg sizes and lengths. The legs of the fillet welds varied by more than 1/32" (1mm) on any one linear segment, making it difficult to measure with accuracy. Consequently, the throat dimensions used in the calculations of shear strength were in all cases based on the average measured length of fillet leg sizes.

Per ANSI/AWS B4.0-85, shear strength in pounds per square inches is determined by dividing the unit shear load in pounds per linear inch by the average theoretical throat dimensions of the sheared weld. To comply with this specification, a 45° shear failure is assumed for both longitudinal and transverse orientations. All practical and theoretical data[13] support a 45° angle for longitudinal failures. However, evaluation of failures from this project and theory from related studies confirm a 22.5° shear angle in transverse specimens. Assuming this to be valid, calculations with 22.5° would decrease the actual shear strength values for transversely welded fillets by 8%.

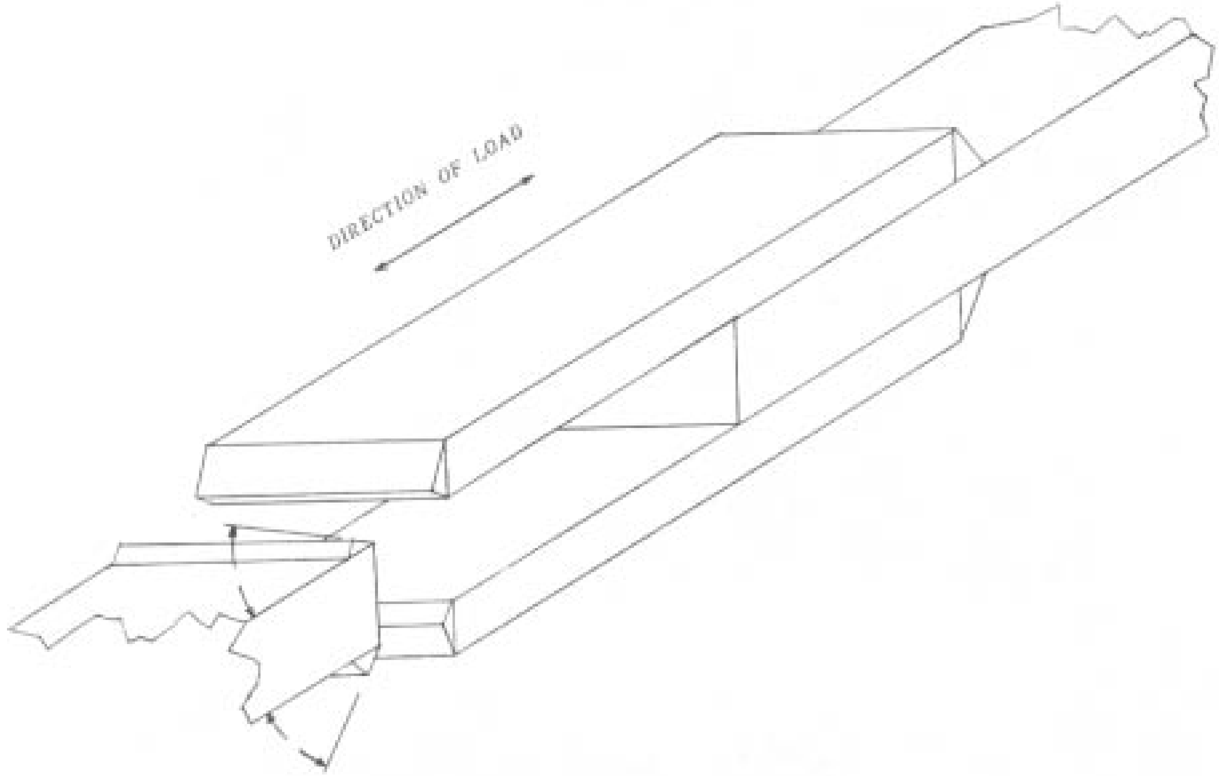


Figure 6. Typical Transverse Shear Failure Angle

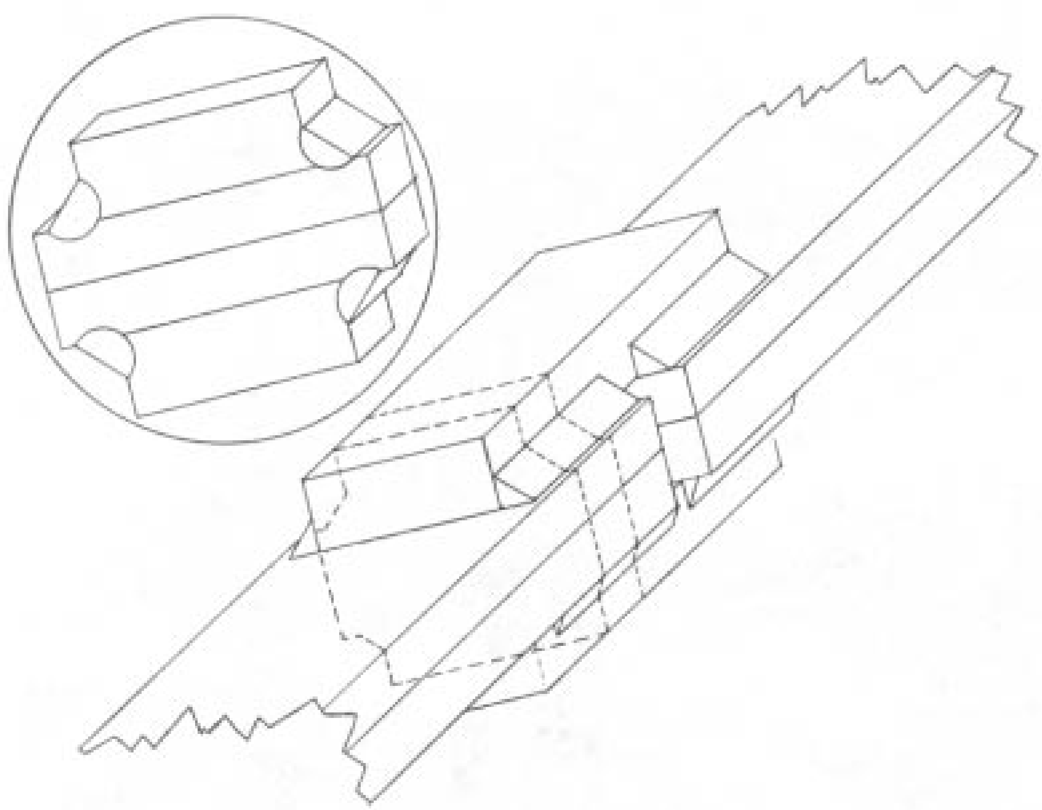


Figure 7. Typical Cross-Section Used For Macroetch of Longitudinal Fillet Weld Test Specimen

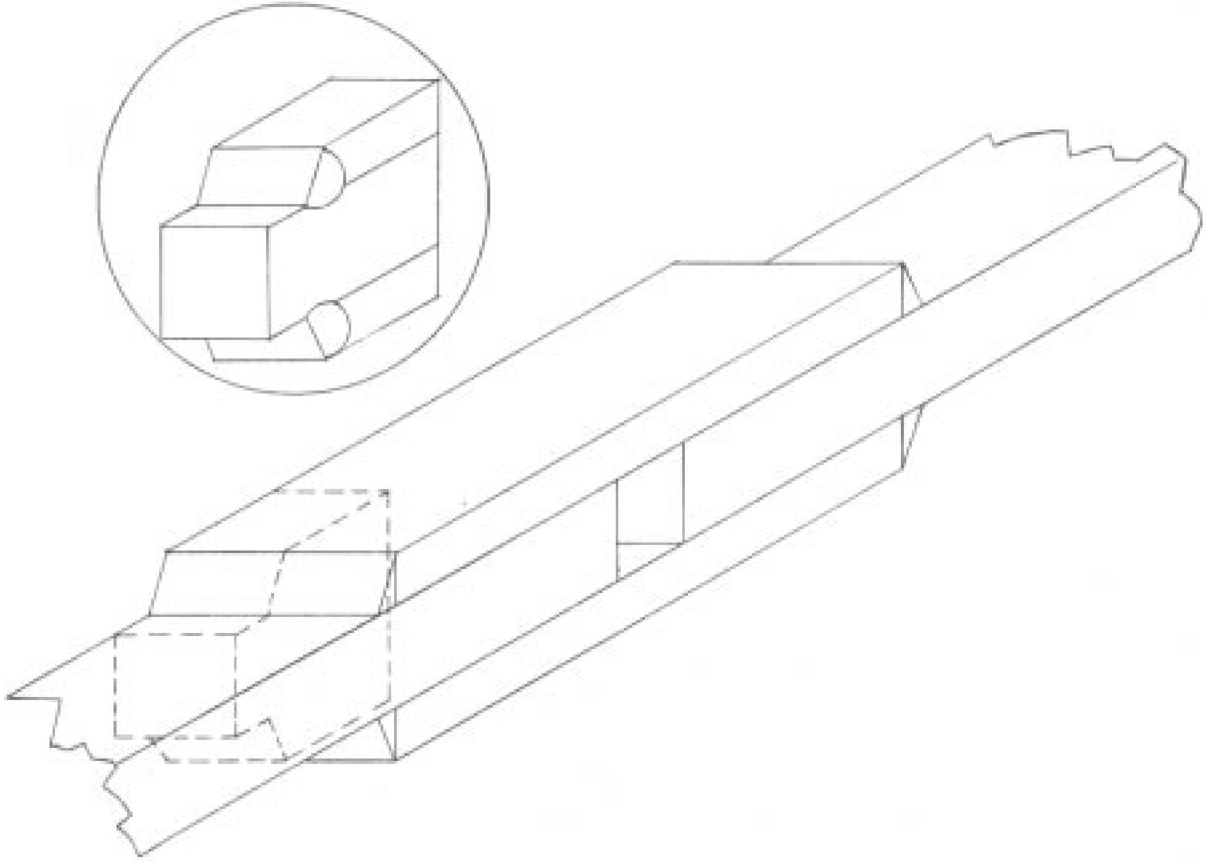


Figure 8. Typical Cross-Section Used For Macroetch of Transverse Fillet Weld Test Specimen

In an investigation to determine a theoretical method of obtaining shear strength in transverse fillet welded joints[14], a formula was derived to show the strength relationships between longitudinal and transverse fillet welds. The theory indicated that the failure path would follow a 22.5° transverse shear angle. Many observations corroborated that theory. The formula stated that transverse shear strengths were 46% greater than the longitudinal. In comparison, data from this project produced transverse shear values 40% greater than longitudinals in welds made with MIL-71T1-HY electrode. A 28% greater strength was produced with the MIL-101-TC/TM electrode. Slight differences in a fillet weld's adjacent leg lengths would change the shear angle to anything but a perfect 22.5°. This and inaccuracies in weld measurements may account for the conflict between practical and theoretical results.

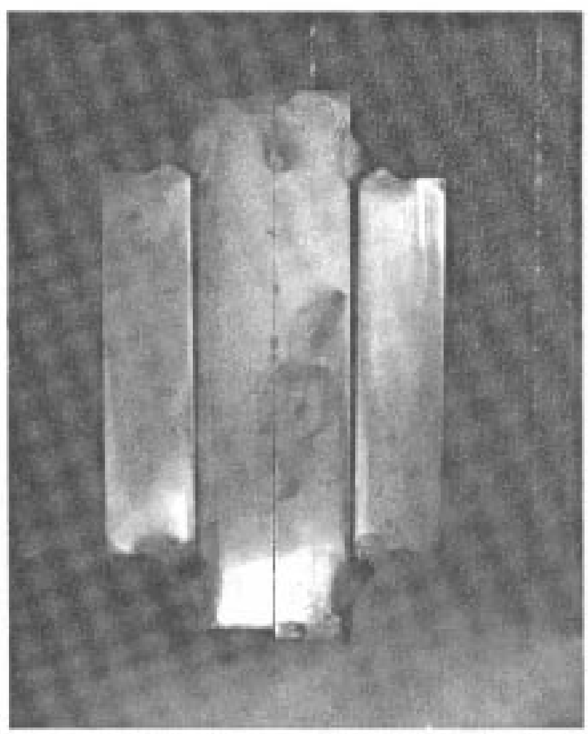


Figure 9. Longitudinal Shear Test Specimen 1A

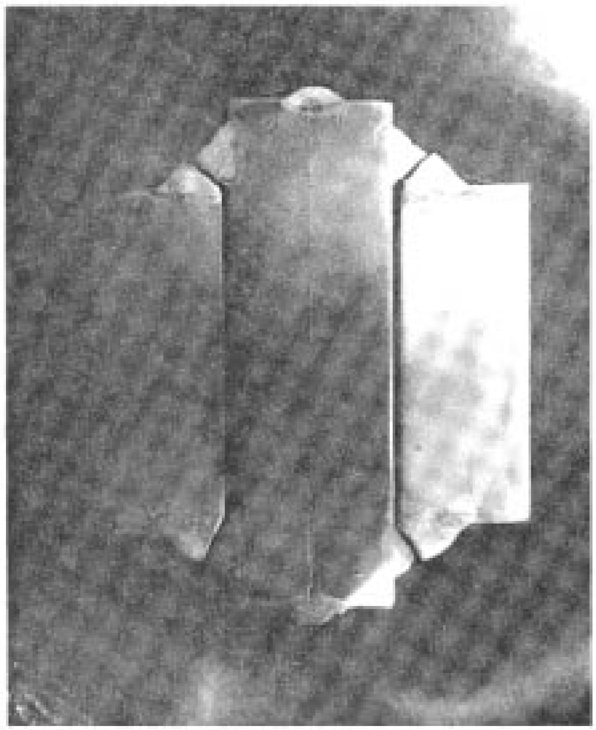


Figure 10. Longitudinal Shear Test Specimen 15A

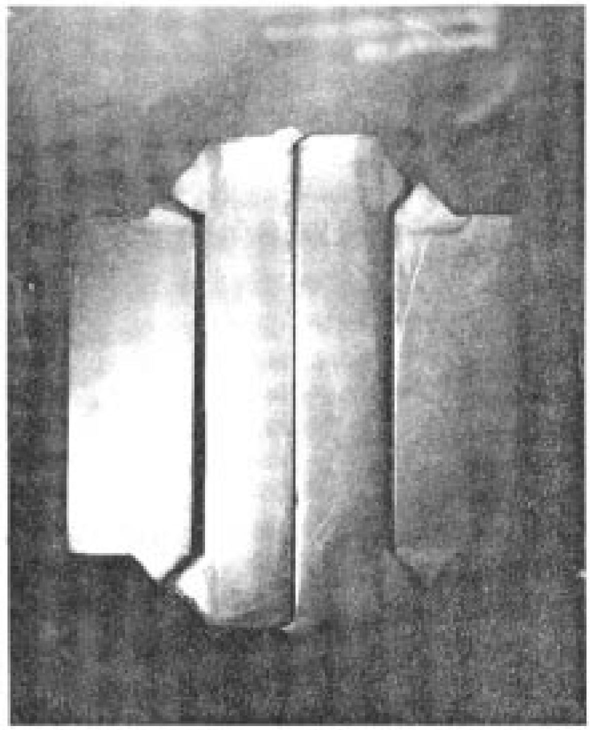


Figure 12. Longitudinal Shear Test Specimen 27A

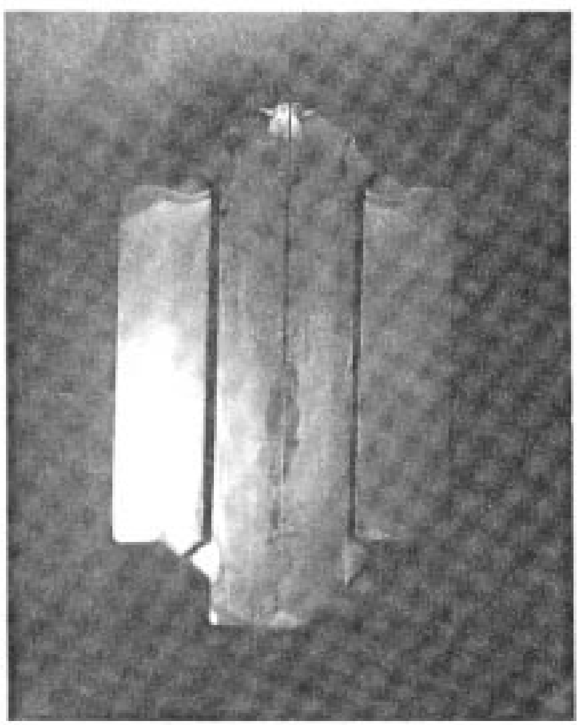


Figure 11. Longitudinal Shear Test Specimen 21A

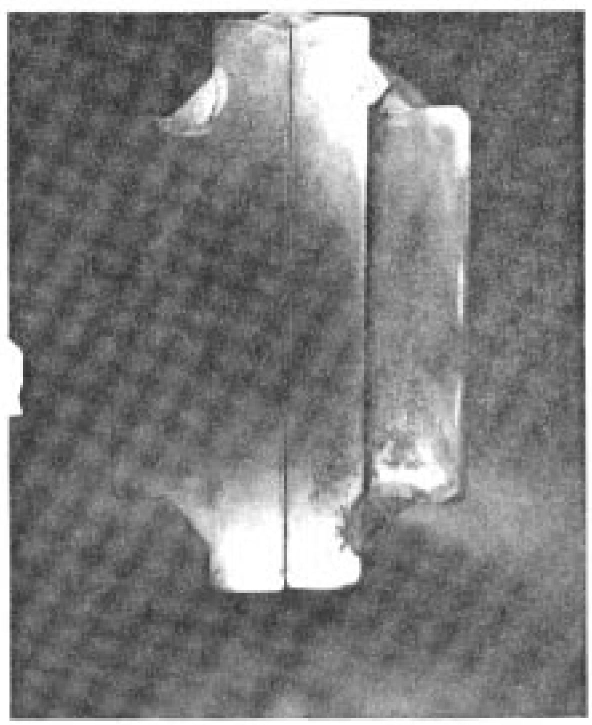


Figure 13. Longitudinal Shear Test Specimen 35A

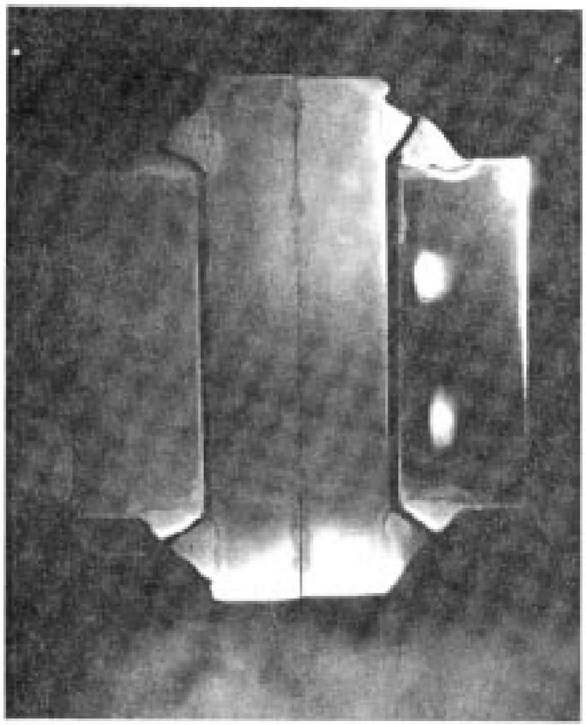


Figure 14. Longitudinal Shear Test
Specimen 45A

Figure 16. Transverse Shear Test
Specimen 15B

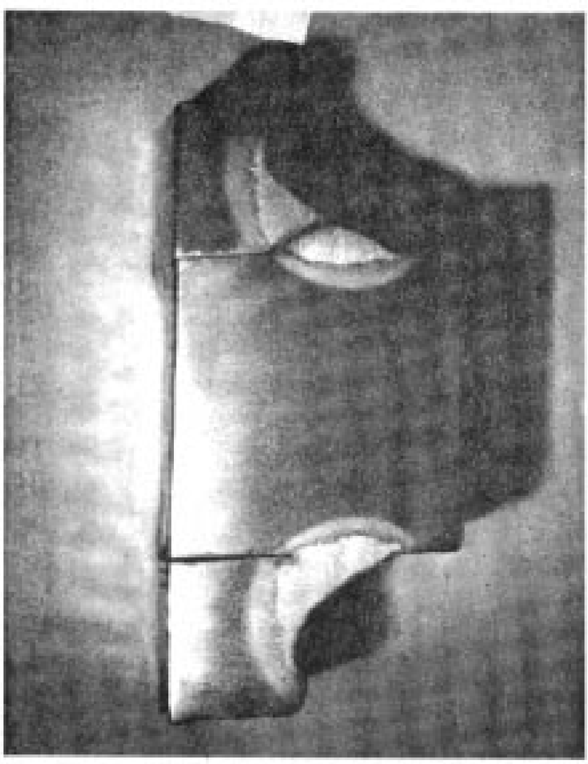


Figure 15. Transverse Shear Test
Specimen 1B

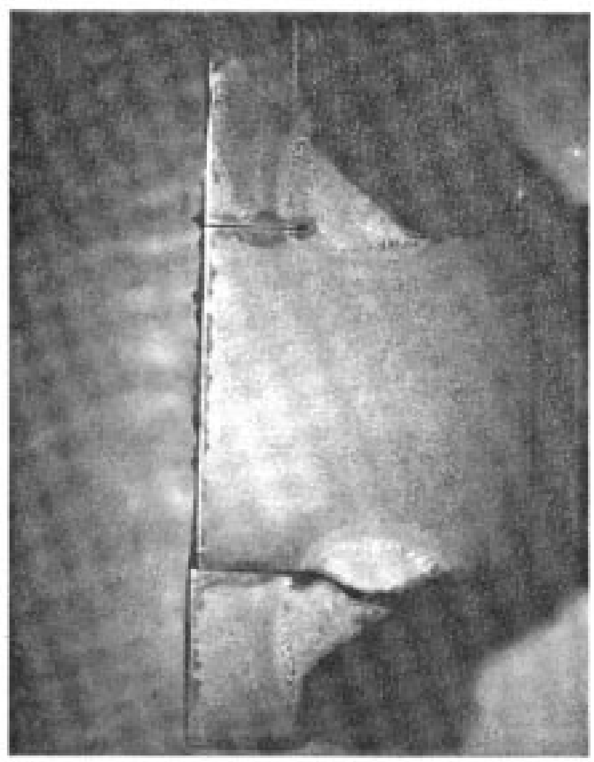


Figure 17. Transverse Shear Test
Specimen 21B

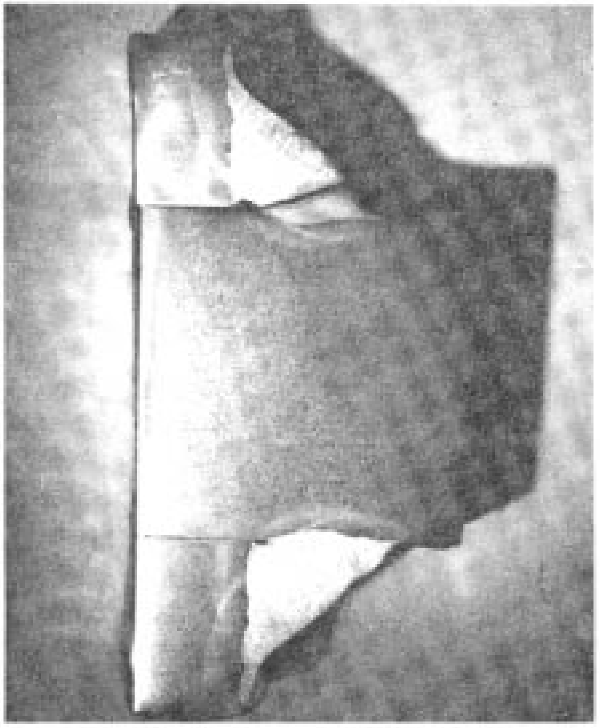


Figure 18. Transverse Shear Test Specimen 25B

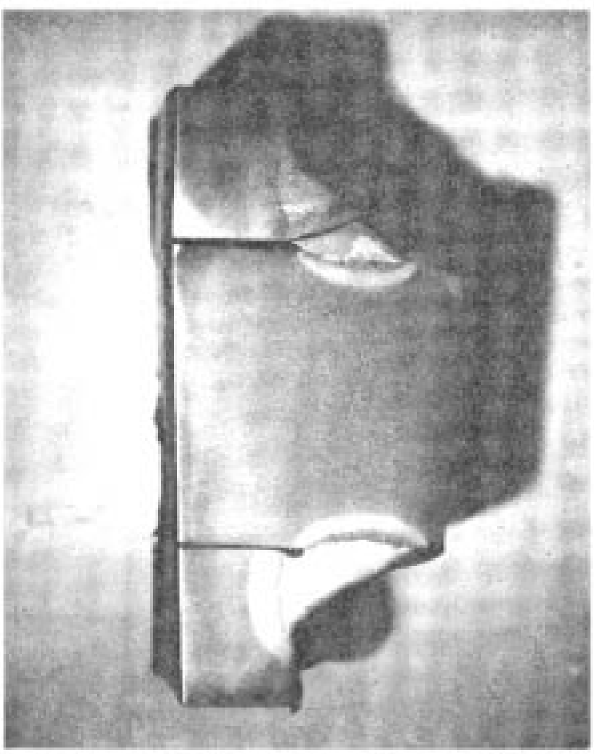


Figure 19. Transverse Shear Test Specimen 35B

Figure 20. Transverse Shear Test Specimen 45B

A major objective of this project was to determine if the increased depth of penetration produced by FCAW would have a beneficial effect on a weld's shear strength. Evaluation of shear failures and macro etches (Figures 9 through 20) of both longitudinal and transverse specimens did not provide strong evidence to support this theory. The metallography shows that the welding parameters used throughout the project do not produce a significant amount of increased penetration in comparison to a similar SMAW deposit. As a result, this data cannot support a definitive answer to the question of depth of penetration and its affect on shear strength.

CONCLUSIONS

The shear strength of fillet welds produced by MIL-71T1-HY is 15% higher than the comparable MIL-70XX SMAW electrode. With the implementation of this data, efficiency tables from MIL-1628 with lower computation factors may be used, thus reducing fillet weld sizes.

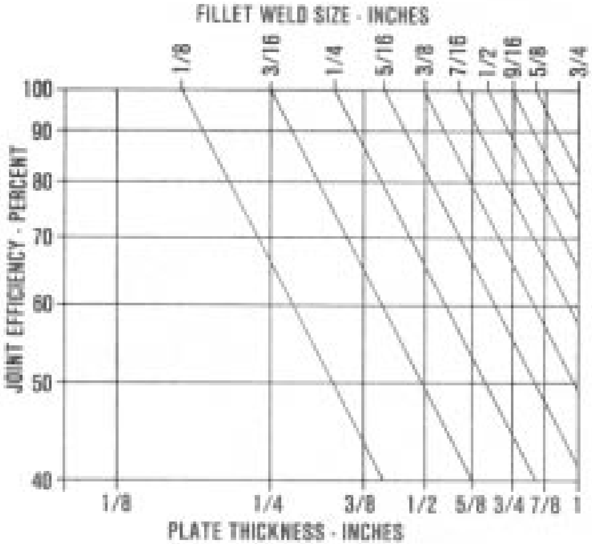


Figure 21. Efficiency Chart For Computation Factor 0.75

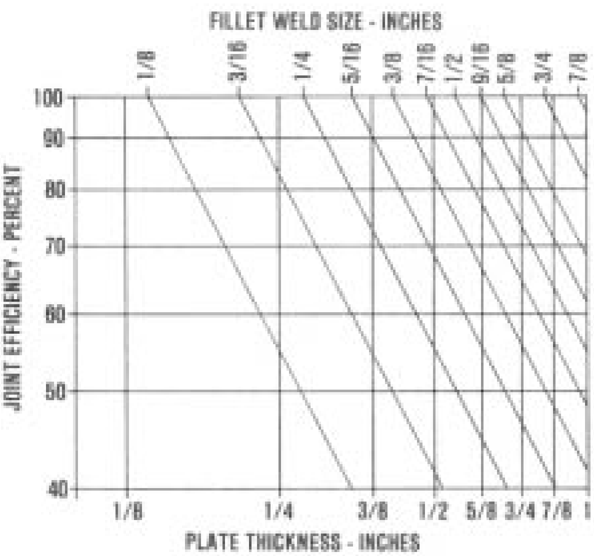


Figure 22. Efficiency Chart For Computation Factor 0.90

As a result of recent shear testing, a potential revision to MIL-STD-1628 may set the longitudinal shear value for MIL-10018M1 at 72 KSI (496 MPa) and decrease the MIL-11018M covered electrode criteria to 79 KSI (545 MPa). The FCAW electrode, MIL-101-TC/TM evaluated in this study, produce 74 KSI (510 MPa), thus supporting the accuracy of these proposed revisions.

The fillet welds tested in this project and related shear studies support a transverse shear failure angle of 22.5°. Empirical observations of this angle indicate a need for a change in the analytical method set forth in ANSI/AWS B4.0-85 of calculating transverse shear strengths.

Evaluating shear failures and macro etches of both longitudinal and transverse specimens produce no evidence that penetration was responsible for increased shear strength. The welding parameters used throughout the project did not produce a significant amount of increased penetration in comparison to a similar SMAW deposit. As a result, the data presented does not purport to answer the question of penetration and its affect on shear strength.

RECOMMENDATIONS

The U. S. Navy should consider revising Table II of MIL-STD-1628 to include the results of the MIL-71T1-HY and MIL-101TC/TM shear testing as follows:

FILLER METAL TYPE	MINIMUM ULTIMATE TENSILE STRENGTH (KSI)	AVERAGE LONG. SHEAR STRENGTH (KSI)
MIL-71T1-HY	70	68
MIL-101TC/TM	100	74

DOUBLE FILLET WELD AVERAGE SHEAR STRENGTH PER LINEAR INCH OF CONTINUOUS WELD (KLI)

FILLET WELD SIZE (INCH)

1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8
12	18	24	30	36	42	48	54	60
13	20	26	33	39	36	52	59	65

Contracts invoking this specification will benefit from the lower computation factors and potentially smaller fillet welds.

The formula for determining fillet weld shear strength under Section 9 of ANSI/AWS B4.0-85 (Standard Methods for Mechanical Testing of Welds) assumes a 45° theoretical throat dimension. Theoretical and practical test results from this and related projects suggests a 22.5° shear angle for transverse shear failures. In view of this information the American Welding Society should consider a revision and or clarification to this specification.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of L. G. Kvidahl, O. J. Davis, W. M. Crawford, W. J. Bryant, T. M. Stampley, and T. R. Warren of Ingalls Shipbuilding for their help in the project and preparation of this paper.

This work is the result of a cost sharing contract between the U. S. Maritime Administration and Ingalls Shipbuilding. The Society of Naval Architects and Marine Engineers Ship Production Committee Panel SP-7 provided the technical guidance for the scope of work.

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3. Type MIL-101-TC/TM, MIL-E-24403/2A

4. "Steel Plate, Alloy, Structural, High Yield Strength (HY-80 and HY-100)," MIL-S-16216

5. "Steel Plate, Sheet, or Coil, Age Hardening Alloy, Structural, High Yield Strength (HSLA-80)," MIL-S-24645

6. Type MIL-7018-M, MIL-E-22200/10A

7. Type MIL-10018-M1, MIL-E-22200/10A

8. "Standard Methods for Mechanical Testing of Welds," ANSI/AWS B4.0-85, Pages 39-42

9. Type AH 36 or DH 36, MIL-S-22698

10. MIL-E-22200/1F, MIL-11018-M

11. MIL-E-23765/2C, MIL-100S-1

12. Mare Island Naval Shipyard, Technical Report 138-4-80, Revision A, December 1980.

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24.1990

Shipboard Aluminum/Steel Welded Transition Joints Evaluations and Improvements

5B-2

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ABSTRACT

Aluminum to steel explosion welded transition joints are used to attach aluminum superstructures to steel hulls. Transition joint bond separation sometimes occurs during ship construction. Ingalls Shipbuilding conducted a long term study to determine causes and corrective action for these separations.

The aluminum/steel transition joints are manufactured by the explosion bonding process and tested in accordance with MIL-J-24445. Traditional transition joints consist of alloyed aluminum bonded to mild steel with an interlayer of low alloy aluminum.

The study reviewed transition joint manufacture and quality testing required by the material specification, reviewed the adequacy of design guidelines and production practices, and considered cost effective methods for corrective action. Modifications in product design and testing, installation design and shipyard production practices can improve reliability. The most important result of this study was development of material with improved Properties. This paper relates the study procedure, findings and recommendations so that transition joint separations can be avoided on future installations. This information is useful for designers and transition joint users.

DESCRIPTION

Aluminum cannot be arc welded directly to steel because of metallurgical incompatibility. Aluminum to steel welds can be produced using cold welding processes, such as explosion welding (EXW). Conventional fusion welding processes then can be made to attache the EXW transition to respective compatible metal components. This combination provides a crevice free, fully welded joint between aluminum and steel. This is a significant advantage over mechanical fastening by riveting or bolting.

The aluminum to steel transition joints typically are welded to a steel coaming about five inches above the topmost steel deck. The transition joint supports the bulkhead plating, vertical stiffeners and framing. The bond surface is parallel to the deck. See Figure 1 for a typical design. Earlier designs used 3.5 cm (1-3/8 inch) thick transition joints. Recent designs use 2cm (3/4 inch) thick transition joints.

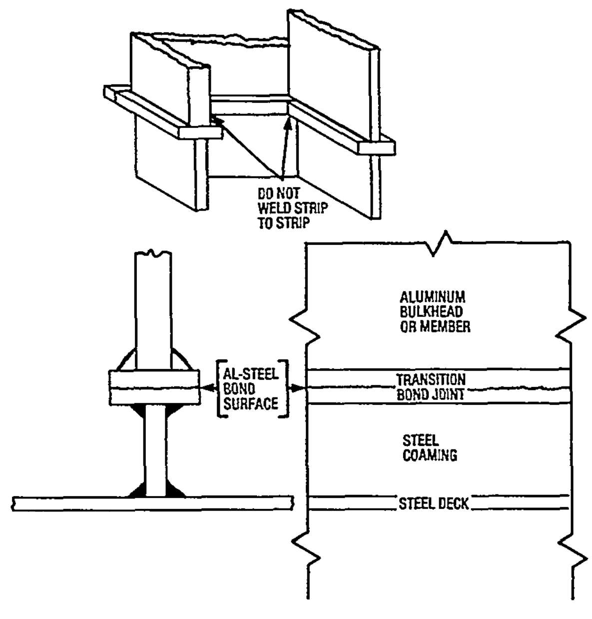


Figure 1. Typical Joint Design

In earlier years, there were few reports that bond separation had occurred. Recently, some bonded joints separated as a result of normal operations in high sea state conditions. These disbonds resulted in closely focused attention on all bond joints. The separations were puzzling because these transition joints were designed to be the "strong link" in the structural chain (stronger than the aluminum plating welded to the joint).

Ships under construction were closely examined. For about a year, locations of disbond repairs were monitored to analyze why the disbonds were occurring. The findings are discussed later in this paper. The study showed that disbonded

lengths were generally short, typically 15-30cm (six to twelve inches) long. Occasionally, longer pieces were replaced because there were several adjacent repairs. All known disbonded locations have always been repaired before any ship left the shipyard. Disbonding in service is rarely reported, so apparently disbond in fleet service is unusual.

Transition Joint Manufacture

Aluminum to steel bonded transition joints are manufactured in accordance with the requirements of MIL-J-24445. Although the specification permits manufacture by several processes, the only process currently used for manufacture of shipboard transition joints in the USA is explosion welding. The basic explosion bonding process is essentially the same for all producers. Reference (1) provides a thorough description of the technology and of the development of aluminum to steel transition joints for shipboard applications. Figure 2 depicts the basic explosion bonding process. The plates to be bonded are fixtured parallel to each other and separated by a gap. A layer of explosive is placed on top of the upper plate. The explosive is a formulation specifically manufactured for explosion bonding; the detonation rate is typically in the 2500 to 3000 meter/second range. The explosive detonation initiates at the edge of the plate, the initiation point. Upon initiation, the detonation front travels across the plate at the detonation rate of the explosive. The gas expansion resulting from detonation accelerates the upper plate downward causing the plates to impact at an angle, typically in the 15 degree range. At the point of impact, surface pressures of several million PSI are developed. These pressures create a spalling condition on the surfaces out in front of the collision point. This spalling condition, or jetting, strips the surfaces clean of oxides and surface contaminants immediately prior to collision. At the collision point, the newly cleaned surfaces are driven into intimate metallurgical contact, resulting in metallurgical welding of the two plates. Under the high pressures and high velocities, a waveform develops at the bond, providing a unique "footprint" exclusive to the explosion welding process. Figure 3 is a cross section of this footprint. During this operation, there is essentially no heat generated at the bond zone. Consequently, this cold welding operation is suitable for jointing materials that cannot be fusion welded, such as aluminum and steel.

If bonding parameters are correct, the explosion bonded plate exhibits relatively uniform strength throughout. A slight reduction in strength may be

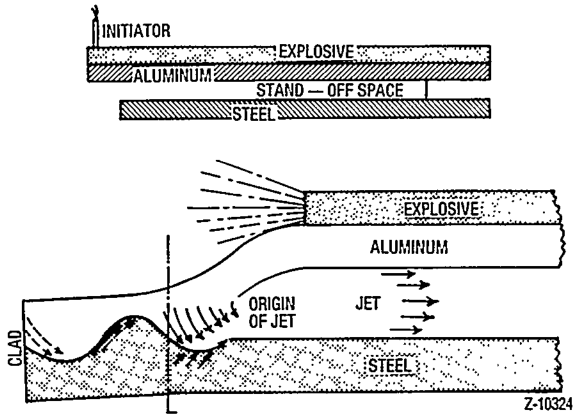


Figure 2. **Parallel arrangement** *for explosion* **cladding and subsequent collision between the prime and** *backer metals that leads to jetting and formation of wavy bond zone.*

Figure 3. Photomicrograph steel to aluminum bond (edge) showing a characteristic wave swirl with a small intermetallic **pocket at the "crest".**

observed near the initiation point. When aluminum is bonded directly to steel, there are isolated pockets of low strength material in the wave swirl, Figure 3. These melt pockets are normally fully surrounded by high strength, ductile material. Significant reductions in overall bond strength can occur if the explosive detonation rate is not adequately controlled. The strength reductions can be associated with areas of melt along the bond zone outside the isolated melt pockets. In general, the permissible range of detonation rates is broad, and proper control of bond uniformity is not an issue.

In the early explosion bonding development work discussed in Reference (1), it was observed that a direct explosion weld between aluminum 5000 series alloys and steel exhibited low strength and poor toughness. The deficiency was corrected by insertion of an interlayer of unalloyed aluminum, type 1100, between the marine grade aluminum and the steel. The original 3.5cm (1-3/8 inch) thick

transition joints consist of thick 5456 aluminum alloy bonded to an interlayer of 0.375 inch thick 1100 aluminum and a base of 0.75 inch steel. Later 2cm (3/4 inch) thick transition joints were made using 0.125 inch thick 5456 or 5086 aluminum alloy bonded to a 0.25 inch thick interlayer of 1100 aluminum and a base of 0.375 inch steel. Although these products are actually comprised of three alloy layers, they are commonly referred to as "bimetallic" transition joints.

Transition Joint Quality Testing

Aluminum to steel welding transition joints are quality tested in accordance with the requirements of MIL-J-24445. This specification requires ultrasonic inspection of every plate. In addition, one plate from every lot, or 1 in 10, whichever is more frequent is mechanically tested. Test specimens are to be cut from two diagonally opposite corners of the selected plates. Either a ram tensile test and a side bend test, or a ram tensile test, bond shear strength test and a chisel test are required. Before testing, samples are heat treated 15 minutes at 600 degrees F. to simulate the "as welded" condition. Specification requirements are: 8,000 PSI minimum shear strength; 11,000 PSI minimum tensile strength; and no bond failure in either the side bend test or the chisel test. All plates are inspected over 100% of the surface by straight beam ultrasonic inspection to detect areas of non-bond. Although ultrasonic testing will reliably detect non-bond, it will not reliably detect areas of low bond strength.

Bond Separations Study

The objective of the study was to determine the cause of disbonding and implement preventative measures. Numerous possible causes of shipboard transition joint disbonding were considered and studied. The study primarily concentrated on the following questions:

(1) Is the bonded transition joint being overheated during shop and field welding?
(2) Are oversize weld fillets causing excessive or uneven stress?
(3) Are there differences between earlier and current materials?
(4) Does the bond material meet MIL-J-24445?
(5) Does MIL-J-24445 provide adequate control over the material?
(6) Are improvements beyond MIL-J-24445 minimums feasible?
(7) Are guidelines for, and design widths of, strips adequate?
(8) Is the restraint effect of the ship's structure significant?
(9) Can the reliability of aluminum-steel transitions be improved?

Examinations of disbonded strips showed all separations occurred at the bond between the 1100 alloy aluminum and the steel. No separations were observed at the 5456 to 1100 alloy aluminum bond. Separated strips showed the characteristic wavy bond surface pattern associated with properly bonded material. Most welds attaching the transition joints to superstructure had large aluminum fillets that typically came out to the edge of the strip. Most steel fillet welds attaching the transition joint to the steel coaming were smaller and did not come to the edge. Most disbonded locations included or were adjacent to butts in strips. Examination of separated locations revealed several cases where full penetration butt joint designs were used instead of the partial penetration butts recommended in Reference (2) and shown in Figure 4. Because aluminum cannot be arc welded to steel, full penetration butt joints are not possible. Full penetration butt joints joining two strips result in local overheating and weakening of a short length of bond (under one inch). Depending on stresses applied to the butt, this small area may initiate global disbond growth through

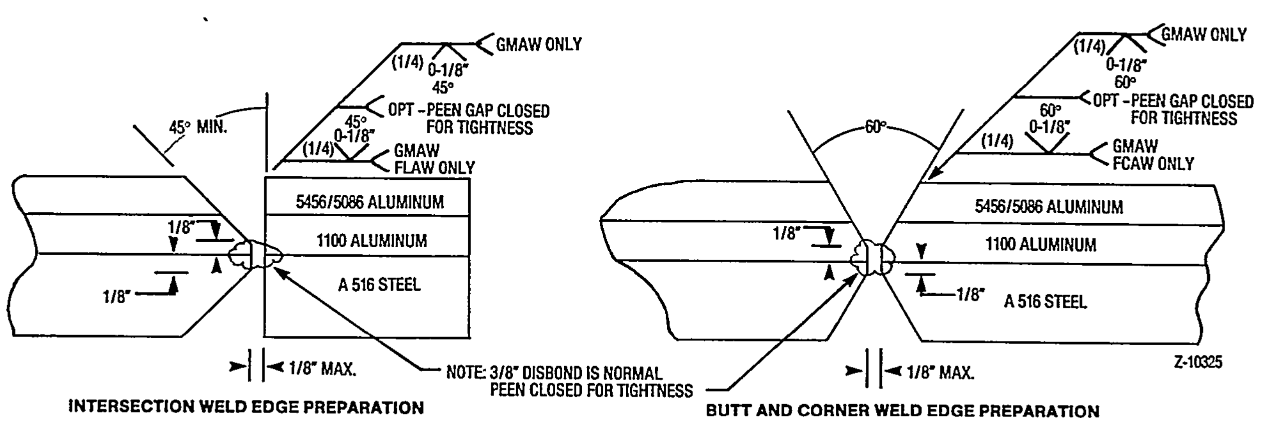


Figure 4. Recommended butt joints in transition strips

peeling. Although the design drawings may show a full penetration symbol, production craftsmen were instructed to use only partial penetration butt welds in transition joints.

Disbonded samples were analyzed by Ingalls, two vendors, and a Navy laboratories. Our chemical lab verified that the proper alloys were used in each layer. Other samples were sent to the two primary transition joint suppliers and to an independent Navy laboratory. Based on microscopic examination of the bond, the joint manufacturers and the Navy laboratory concluded that there was a possibility that the transition joint had been overheated (probably during welding). Based on this preliminary finding, production welding of transition joints to ship's structure was switched from spray arc (flux cored for steel) to pulsed GMAW (Gas Metal Arc Welding). This change was made to lower heat input and peak temperature at the bond zone.

Evaluation Of Welding Heat Input Effects

Since aluminum and steel are not metallurgically compatible at elevated temperatures, the aluminum to steel bond zone can be degraded by excessive heating. Transition joint manufacturers recommend that bimetallic aluminum to steel transition joints not be heated over 315°C (600°F). during installation. Table I presents strength data for bimetallic transition joints under various thermal conditions. Note, there are significant reductions in strength after relatively short time excursions above 371°C (700°F). Also, note that the strength of the product is significantly reduced when tested at elevated temperatures.

Tests were conducted in our welding lab to determine the temperature at the

TABLE I
TEMPERATURE EFFECTS ON
TRANSITION JOINT STRENGTH

MAT'L	PEAK TEMP	TEST TEMP	RAM TENSILE
BI	70'F	70'F	14,527
BI	600'F	70'F	12,221
BI	800'F	70'F	7,150
BI	1000'F	70'F	3,812
BI	600'F	300'F	9,600
BI	600'F	600'F	6,215
TRI	70'F	70'F	26,839
TRI	600'F	70'F	23,140
TRI	1000'F	70'F	18,012

BI = BIMETALLIC JOINT
TRI = TRIMETALLIC JOINT

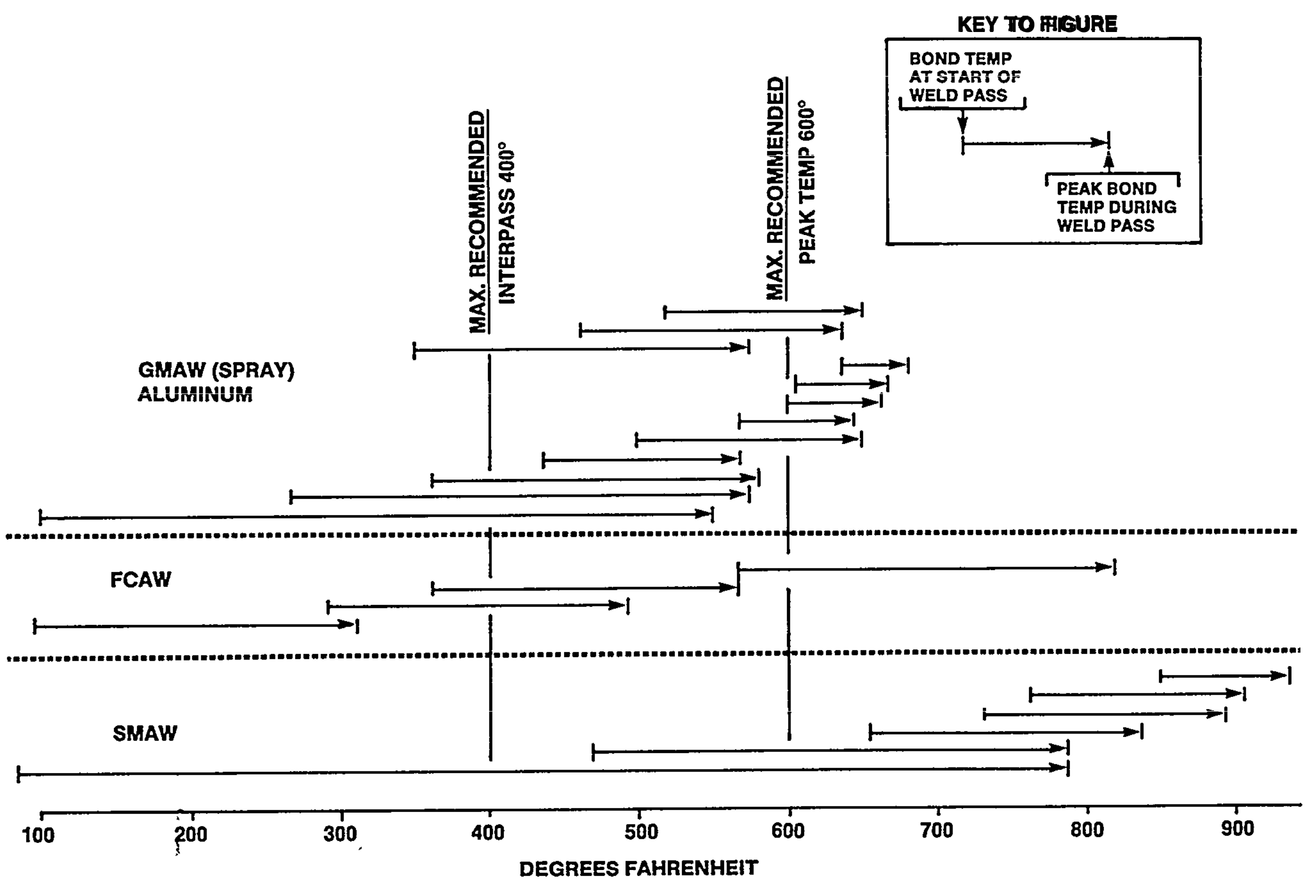


Figure 5. Weld interpass and peak temperatures

bond during various weld processes. Holes were drilled from the back side to the bond joint, and digital thermocouples were used to measure temperatures. A spray arc aluminum single pass weld resulted in a peak bond joint temperature of 274°C (525°F) for 2cm (3/4 inch) strips and 254°C (490°F) for the 3.5cm (1-3/8 inch) thick strips. A 12 pass full penetration aluminum weld with NO cooling period between passes resulted in a worst case peak bond joint temperature of 343°C (650°F). Aluminum welding tests showed that if the interpass temperature was below 204°C (400°F), peak temperature at the bond joint was below limiting temperature of 315°C (600°F), regardless of process.

Steel welding resulted in considerably higher temperatures at the bond. Multi-pass (no interpass cooling) with SMAW (shielded metal arc welding) process resulted in 499°C (930°F) at the bond joint. A similar weld with FCAW (flux core arc welding) process resulted in a peak temperature of 435°C (815°F), but, compared to SMAW, a shorter duration above the limiting temperature. SMAW is clearly unsuitable for welding transition joints within the allowable bond joint temperature envelope. Both semi-automatic GMAW (gas metal arc welding) and FCAW complying with the 204°C (400°F) interpass temperature limit resulted in acceptable peak temperatures at the bond surface. Figure 5 graphically illustrates the relationship between process, interpass, and peak temperatures.

The welding lab's tests showed that production fillet welding probably did not overheat the joint. SMAW could have caused thermal degradation. However, SMAW was not used for this application. Most of the separations were observed where single pass fillets were used. Based on this data, the production welding processes in use were not the likely cause of disbonding. As a preventative measure, though, welding continued with the pulsed arc GMAW process, which has the least heat input of any process permitted by the ship's specifications. One of the manufacturers recommended short circuiting GMAW for the steel attachment weld. Short arc is an even lower heat input process than pulsed arc. However, the short arc process is not permitted in this application by the U. S. Navy's specifications.

Production experiences corroborated the laboratory test results above. Production welding clearly showed that complying with temperature limits would not prevent separation. Hulls welded entirely with pulsed GMAW process did not show noticeable change in transition joint reliability. Bulwarks on one of the ships were field welded in strict compliance with temperature limits. Every welding pass was monitored by shipyard and Navy Quality Assurance inspectors. Still, disbonding was found after depositing as few as three passes. In another case, welding of aluminum to a transition joint in a shop was closely monitored. This configuration of the deck pad permitted Ultrasonic Testing (UT) before and after welding the aluminum to the transition. Several internally disbonded areas were detected by UT after welding (internal disbonds cannot be found visually). Cross sectioning of the pad confirmed separation at the indications. This occurrence was later duplicated under laboratory conditions. Similar production experiences indicated the need to look for other possible causes.

Transition Joint Manufacturer Visits

Visits to the transition joint manufacturer's facilities were arranged as part of our shipyard's regular program of supplier review. Both manufacturers had been involved in the study since it's inception, and each visited the shipyard to review end use of the product. Separated samples had been provided to both, and their analysis welcomed. Discussions during the visits also provided further avenues for study and improvements. Both manufacturers demonstrated that they were in compliance with the testing and quality control requirements of MIL-J-24445. Additional testing demonstrated that the test program of MIL-J-24445 may not reliably prevent lower strength bond material from reaching the ships. To some extent, bond manufacturers recognize this. For example, they routinely trim material beyond the areas rejectable under MIL-J-24445.

MIL-J-24445 requires test samples to be taken from opposite corners of a sample transition plate. However, weaker or more brittle bonds are usually found adjacent to the explosion initiation point. Test samples were taken adjacent to the initiation point (not a location required by MIL-J-24445 to be sampled) of plates which had already proven adequate at the required test locations. The samples taken near the initiation point showed noticeable reduction in bond strength and increased susceptibility to disbonding during "chisel testing," a qualitative test of bond ductility. Areas that far exceeded the minimum tensile and shear values failed chisel testing. Also, areas that passed the ultrasonic test criteria had bond strength below specification requirements.

Strip Widths

One possible way to compensate for lower actual strength of transition strips is to widen the strips. Wider strips improve the safety margin. Increasing the minimum width will also

increase standardization (by deleting the narrower sizes) for improved producibility. This recommendation from one of the manufacturers lead to a study of strip widths.

Reference (2) recommends sizing joints as follows:

> "a rule of thumb for joining aluminum and steel plate is to use a transition bar four times as wide as the thickness of the aluminum being welded to it. In general, the 4-to-1 rule is conservative and recommends a transition joint larger than is actually needed."

The minimum ultimate tensile strength of 5456-H116 aluminum alloy 6527kPa (45,000 PSI) is 4.09 times the minimum ultimate tensile strength of transition joint required by MIL-J-24445 1595kPa (11,000 PSI). Most of the known disbonds were found in strips that were in compliance with the 4-to-1 rule of thumb. Tests of production welded material demonstrated tensile values exceeding the requirements of MIL-J-24445. In theory, failure should always occur in the weaker bulkhead plating, never in the stronger bond. As the aluminum is not designed to reach ultimate stress under design loads, 4-to-1 should be conservative. Based on the number of disbonds experienced, this supposition must not be correct. What is the cause?

Perhaps statistics can help answer this question. The bond quality testing performed by the manufacturers show properties exceeding the minimum required by MIL-J-24445. The aluminum bulkhead plate is also stronger than the minimum. What ratio statistically provides a reliable bond joint stronger than the aluminum?

Testing was performed using welded tensile test specimens of the general design for first article testing by MIL-J-24445. It is important to note that these tests are very different from the ram tensile tests performed by the bond manufacturers. The width ratio of the transition strip and the aluminum plating were altered to assure failure of the explosion bond. The complete listing of all tests with separations in the transition strip is in Appendix A. Table II shows a summary of the strengths of strips welded to represent typical production practices. The average (50 percentile) strength of the welded strips is about 2172kPa (14,978 PSI). The average strength of our aluminum bulkhead plating is 7411kPa (51,100 PSI). If the ratio of these stresses is used (3.4 to 1) to size strip width to aluminum plate thickness, at ultimate load, the aluminum base material or weld will fracture half the time. The rest of the time, the bond will separate (assuming 100% efficient welds).

However, the average does not tell the whole story. To account for scatter, the average and standard deviation are used to calculate the 99 percentile stress, based on standard random (bell curve) distribution of the entire population. The 99 percentile stress (MIN99) is the expected value where 99% of the ultimate stresses measured will be above that point, and 1% will be below. If we use the average aluminum plate ultimate tensile stress divided by the 99 percentile strength of the bond joint (12,050 PSI based on the data from Table II) to get a recommended ratio of 4.24 to one, we can expect about one percent of the failures types to be bond separation. This is very close to the actual separation rate experienced for ships under construction during the study. If this degree of reliability is not acceptable, the ratio can be markedly reduced if the tensile strength of the bond joint is improved as discussed later in the paper.

Effects of Installation Restraint On Bond Strength

One hypothesis for the cause of bond separation was that the restraint provided by surrounding ship's structure during construction (but not in laboratory testing) could produce residual stresses that would lower effective bond strength and contribute to separation. As the aluminum has a low modulus of elasticity, stress may concentrate in the more rigid bond joint (steel has a higher modulus). Furthermore, restraint causes thermal shrinkage stresses to be applied to the bond joint while the bond is at an elevated temperature due to welding. Tensile strength of the 1100

TABLE II
SAW CUT BIMETALLIC
BOND STRENGTHS

SEQ NUM	ULT STRESS	
5	N/A	
10	12,855	
14	13,590	RESTRAINED
16	13,965	SAMPLE
18	16,084	STATISTICS
19	15,880	AVG =14,978
21	16,251	STD DEV= 1,257
23	16,286	MIN99 =12,050
28	16,124	
32	16,655	
38	14,508	
40	14,268	
41	13,978	
43	14,677	
46	12.057	
47	14,873	
49	14,336	
51	14,149	
53	14,293	
26	15,920	
30	16,481	
34	16,168	
36	16,123	

alloy aluminum and the bond strength decreases as temperature increases. Data for temperature effects on bond strength is shown in Table I and figure Figure 6. A restraint fixture rigidly held some test pieces while welding. Welding with structure restrained reduced the 99 percentile ultimate stress (MIN99 in Table III) about 10%, but did not cause any immediate separations. Pertinent test data from Appendix A is summarized in Table III.

Maximum Interpass Temperature

Another hypothesis for separation was that the peak temperature limits were set too high. Test pieces with reduced interpass temperature were welded in the restraint fixture to see if the 315°C (600°F) peak limit recommendation was too optimistic. Reducing the interpass temperature from 204 to 66OC (400 to 150°F) showed about 10% improvement in the average ultimate bond stress and 16% improvement in the 99 percentile stress. Pertinent test data from Appendix A is summarized in Table IV.

Effect of Welds Transverse To Bond

Disbonds frequently had been associated with butts in transition joints, which. are usually found at butts and intersections in bulk was again used to study the possibility that plating welds

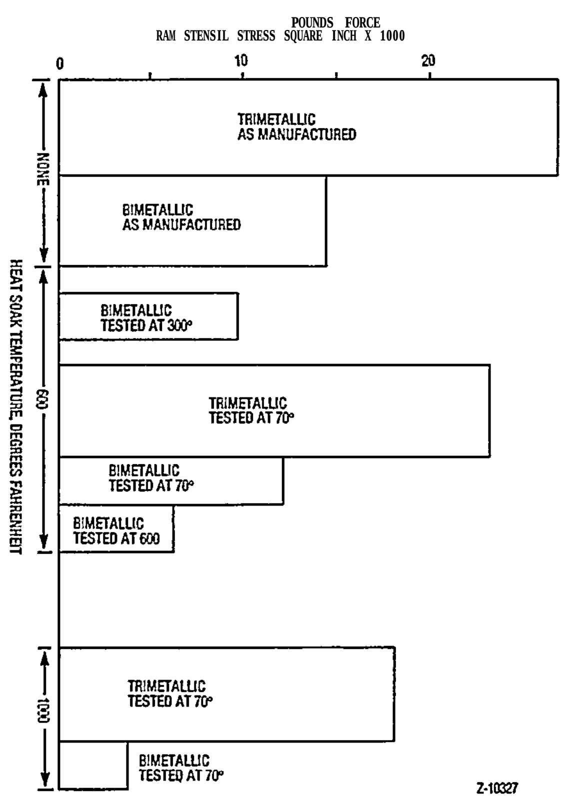


Figure 6. Heat effects on bond strength

TABLE III
EFFECT OF RESTRAINT DURING
WELDING ON BOND STRENGTH

SEQ NUM	REST-RAINT	ULT STRESS	SEQ NUM	REST-RAINT	ULT STRESS
5	YES	N/A	13	NO	15578
10	YES	12855	15	NO	16860
14	YES	13590	17	NO	15775
16	YES	13965	20	NO	16518
18	YES	16084	22	NO	15930
19	YES	15880	24	NO	15946
21	YES	16251	25	NO	16287
23	YES	16286	31	NO	15939
28	YES	16124	37	NO	14773
32	YES	16655	39	NO	14429
38	YES	14508	42	NO	15765
40	YES	14268	44	NO	15179
41	YES	13978	45	NO	13615
43	YES	14677	48	NO	15012
46	YES	12057	50	NO	13918
47	YES	14873	52	NO	14676
49	YES	14336	54	NO	14914
51	YES	14149	27	NO	15263
53	YES	14293	29	NO	14196
26	YES	15920	33	NO	16198
30	YES	16481	35	NO	16742
34	YES	16168			
36	YES	16123			

RESTRAINED STATISTICS		UNRESTRAINED STATISTICS	
AVG =	14978	AVG =	15405
STD DEV =	1257	STD DEV =	898
MIN99 =	12050	MIN99 =	13313

TABLE IV
EFFECT OF MAX WELDING TEMP
ON BOND STRENGTH

SEQ NUM	ULT STRESS	INTERPASS MAX TEMP	SEQ NUM	ULT STRESS	INTERPASS MAXTEMP
5	N/A	150`F	42	15765	400`F
10	12855	150`F	43	14677	400`F
13	15578	150`F	44	15179	400`F
14	13590	150`F	45	13615	400`F
15	16860	150`F	46	12057	400`F
16	13965	150`F	47	14873	400`F
17	15775	150`F			
18	16084	150`F			
19	15880	150`F			
20	16518	150`F			
21	16251	150`F			
22	15930	150`F			
23	16286	150`F			
24	15946	150`F			
25	16287	150`F			
26	15920	150`F			
27	15263	150`F			
28	16124	150`F			
29	14196	150`F			
30	16481	150`F			
31	15939	150`F			
32	16655	150`F			
33	16198	150`F			
34	16168	150‘F			
35	16742	150`F			
36	16123	150‘F			

BOO'DEG. STATISTICS	
AVG =	14361
STD DEV =	1216
MIN99 =	11529

150 DEG. STATISTICS	
AVG =	15744
STD DEV =	996
MIN99 =	13423

transverse to the bond were causing residual welding shrinkage stresses sufficient to partially disbond or weaken the transition joint. The average ultimate stress with a plate butt transverse showed a 1% improvement, and a 7% improvement in the 99 percentile stress. Pertinent test data from Appendix A is summarized in Table V.

The above results contradict logic and the actual increase of disbond frequency at butt welds. In later tests, 10mm (3/8") diameter holes were drilled through the bond zone about 1/2 inch from each end of the sample. The radius notched samples separated at 12.4% lower average stress. Pertinent test data from Appendix A is summarized in Table VI. This supports the conclusion that the transition strip butt weld geometry contributes to the frequent separations in this region (in addition to the temperature effects already known).

TABLE V
EFFECT ON BOND STRENGTH OF PLATE BUTT WELD TRANSVERSE TO BOND

CG53 MATERIAL, 150'F. INTERPASS

SEQ NUM	PL BUTT	ULT STRESS	SEQ NUM	PL BUTT	ULT STRESS
5	NO	N/A	26	YES	15920
10	NO	12855	27	YES	15263
13	NO	15578	29	YES	14196
14	NO	13590	30	YES	16481
15	NO	16860	33	YES	16198
16	NO	13965	34	YES	16168
17	NO	15775	35	YES	16742
18	NO	16084	36	YES	16123
19	NO	15880			
20	NO	16518	WITH XVERSE BUTT		
21	NO	16251	AVG =15,886		
22	NO	15930	STD DEV = 755		
23	NO	16286	MIN99 =14,126		
24	NO	15946			
25	NO	16287	W/O XVERSE BUTT		
28	NO	16124	AVG =15,678		
31	NO	15939	STD DEV = 1,085		
32	NO	16655	MIN99 =13,149		

TABLE VI
EFFECT OF ROUNDED NOTCH ON BOND STRENGTH

ALL MATERIAL IS TRIMETALLIC

SEQ NOM	NOTCH	ULT STRESS	SEQ NUM	NOTCH	ULT STRESS
70	YES	21,594	66	NO	22,119
73	YES	20,102	69	NO	26,006
74	YES	20,192	71	NO	26,544
78	YES	20,991	72	NO	28,201
79	YES	23,400	76	NO	25,581
83	YES	26,041	77	NO	26,799
84	YES	22,744			
87	YES	29,077			

NOTCH STATISTICS	NORMAL STATISTICS
AVG = 23,018	AVG 25,875
STD DEV= 2,930	STD DEV 1,867
MIN99 = 16,190	MIN99 21,524

Old Vs.Current Bond Material

Reports that disbonding had *only* recently increased led to a study of whether the strength of the materials had changed. During the manufacturer visits discussed earlier, testing records were examined, but did not support a significant decrease in material properties with time. Several feet of transition joint material manufactured 3-5 years earlier than the current material was located and tested. There was only a 7% difference between old and current material averages, but the 99 percentile stress actually improved. Pertinent test data from Appendix A is summarized in Table VII.

ALTERNATIVE TRANSITION JOINT MATERIALS

The above studies clearly indicated that an increase in minimum bond strength and an increase in permissible weld temperatures would be beneficial. It is well known among explosion bond manufacturers that the insertion of a thin titanium interlayer between

TABLE VII
BOND STRENGTH VARIATION WITH TIME (ABOUT 4 YEARS APART)

SEQ NUM	ULT STRESS	HULL MATL	SEQ NUM	ULT STRESS	HULL MATL
5	N/A	CG53	37	14773	CG65
10	12855	CG53	38	14508	CG65
13	15578	CG53	39	14429	CG65
14	13590	CG53	40	14268	CG65
15	16860	CG53	41	13978	CG65
16	13965	CG53	48	15012	CG65
17	15775	CG53	49	14336	CG65
18	16084	CG53	50	13918	CG65
19	15880	CG53	51	14149	CG65
20	16518	CG53	52	14676	CG65
21	16251	CG53	53	14293	CG65
22	15930	CG53	54	14914	CG65
23	16286	CG53			
24	15946	CG53	CG 65 STATISTICS		
25	16287	CG53	AVG = 14.438		
26	15920	CG53	STD DEV = -336		
27	15263	CG53	MIN99 = 13,655		
28	16124	CG53			
29	14196	CG53			
30	16481	CG53			
31	15939	CG53			
32	16655	CG53			
33	16198	CG53			
34	16168	CG53			
35	16742	CG53			
36	16123	CG53	CG 53 STATISTICS		
42	15765	CG53	AVG = 15,477		
43	14677	CG53	STD DEV = 1,177		
44	15179	CG53	MIN99 = 12,734		
45	13615	CG53			
46	12057	CG53			
47	14873	CG53			

aluminum and steel will achieve both of these objectives. This solution was employed to improve the reliability of the transition joint rings used to insert steel aircraft tiedowns into the aluminum flight decks of the Aegis class ships. The addition of titanium does not, however, eliminate the need for the 1100 aluminum interlayer. The alloying elements of 5456 aluminum are not metallurgically compatible with titanium at elevated temperatures.

In support of this need, Explosive Fabricators introduced a new transition joint product under the trade name Duratemp. The product consists of 5456 aluminum bonded to steel with both an 1100 aluminum interlayer and a titanium interlayer. Duratemp is generically referred to as trimetallic. It is manufactured in the same overall sizes and thicknesses as the bimetallic product. The term "bimetallic" actually refers to a product which has three metals (triclad); one steel and two different aluminum alloys. The term "trimetallic" similarly refers to a product which has four metals (quadclad); one steel, one titanium, and two different aluminum alloys.

The trimetallic material tests showed clearly superior properties. Tensile and shear strengths are much greater than the minimum required by MIL-J-24445, and significantly greater than the average properties of conventional bimetallic bonds. Furthermore, trimetallic remains strong to much higher temperatures 538 vs. 315°C (1000 vs. 600°F). Also, it is the only transition joint which can reliably pass the bend test of MIL-J-24445.

A decision was made to pursue implementation of trimetallic material as a long term improvement. Explosive Fabricators undertook the first article test program required by MIL-J-24445. Other manufacturers are in the process of first article testing. Appendix B lists the measured properties of first article test results for the Duratemp trimetallic product. In addition to testing of 315°C (600°F) heat treated samples as specified in MIL-J-24445, tests were also performed after a heat treatment at 538°C (1000°F) to simulate extreme conditions. Test results were so clearly superior in every respect, not only to the minimum requirements, but also to the actual bimetallic product properties, that Reference (3) approved the use of trimetallic material saying:

> "We approve this product for use on U.S. Navy ship applications which specify use of Aluminum Steel Bimetallic transition joints required in MIL-J-24445."

Independent testing at Ingalls Shipbuilding of welded trimetallic samples showed an increase in the average ultimate stress of 76%. Pertinent data from Appendix A is summarized in Table VIII. Ram tensile data taken from the first six production plates is presented in Table IX. Note that ram testing is a different method than used for our testing.

Cost Considerations

Trimetallic transition joint material costs approximately slightly more than bimetallic material. The increased material cost for the trimetallic material prompted a study of ways to reduce the cost. Four cost reduction factors are considered: strip cutting, strip width, strip thickness and welding.

Strip cutting. Both major manufacturers cut bimetallic transition joint material by sawing. They recommended against the use of the lower cost plasma cutting approach due to concerns over thermal bond degradation. This recommendation was based on tests made in the 1960°s during development of the 3.5cm (1-3/8 in.) thick bimetallic transition plates. Since that time, the material is now 45% thinner, 2cm (3/4 in.), permitting higher plasma torch travel speeds (lower heat input). In addition, the

TABLE VIII
TRIMETALLIC VERSUS
BIMETALLIC BOND STRENGTHS

UNRESTRAINED, 400°. INTERPASS

SEQ NUM	MAT'L	ULT STRESS	SEQ NUM	MAT'L	ULT STRESS
37	BI	14,773	66	TRI	22,119
39	BI	14,429	69	TRI	26,006
42	BI	15.765	71	TRI	26,544
44	BI	15;179	72	TRI	28,201
45	BI	13,615	76	TRI	25,581
48	BI	15,012	77	TRI	26,799
50	BI	13,918			
52	BI	14,676			
54	BI	14,914			

BIMETALLIC STATISTICS		TRIMETALLIC STATISTICS	
AVG =	14,698	AVG =	25,875
STD DEV=	612	STD DEV=	1,867
MIN99 =	13,271	MIN99 =	21,524

TABLE IX
EARLY TRIMETALLIC
RAM TENSILE DATA

SAMPLE NUMBER	NO HEAT TREAT	600'F TREAT	1000'F TREAT
1	24,771	24,941	18,058
2	28,046	21,339	18,764
3	27,356	**N/A**	.17,931
4	27,021	**N/A**	16,092
5	27,523	**N/A**	20,455
6	26,316	**N/A**	16,774
AVG=	26,839	23,140	18,012
STD DEV=	1,063	1,801	1,400
MIN99=	24,363	18,944	14,750

shipyards now have more powerful numerically controlled plasma cutting machines capable of sustained high travel speeds.

Because the original testing was done so long ago, some narrow test strips were plasma cut from bimetallic and trimetallic 2cm (3/4 in.) thick plates. A numerically controlled high power plasma torch cut the strips from transition plates at high speed, 89cm/min (35 IPM). The plates were *not* submerged in water (which would cool it further), but there was a normal cooling and muffling water jacket. The strips were welded to steel and aluminum bars, then pulled apart. Because of differences between the various manufacturer's bimetallic products, plasma cutting strips from one manufacturer's bimetallic plate showed 41% increase in average ultimate stress over the saw cut strips purchased from another manufacturer. Please note that all manufacturer's products exceeded the minimums required by MIL-J-24445, even after plasma cutting. Plasma cut trimetallic material was even stronger than the strongest of the bimetallic products. In fact, it was difficult during testing to disbond the trimetallic transition joint before the welds or base materials fractured. Testing showed that there was no significant difference (1%) between plasma and saw cut trimetallic strips cut from the same plate (lower part of Table X). Pertinent data from Appendix A is summarized in Table X.

Plasma cutting of the trimetallic material offers additional advantages. If bars are cut in situ, only plate need be purchased, greatly reducing current bar inventory. Plasma cutting would permit manufacture of single piece tee connections, resulting in a reduction in the number of complex butt joints.

Transition joint width. The higher strength of the trimetallic joint should permit a reduction in the strip width to aluminum plate thickness ratio. Initial calculations indicate that a ratio reduction to 3:1 may be justified.

Transition joint thickness. The improved elevated temperature performance of trimetallic transition strips should permit use of thinner transition joint components, further reducing costs (and weight).

Welding costs. An increase of permissible interpass temperatures, which should be acceptable for trimetallic bars, might result in a reduction in welding labor costs due to more productive welding processes and shorter waits for interpass cooling.

CONCLUSIONS

No single cause for the bond separations could be isolated. Several significant factors could be occurring synergistically to cause failures including:

(a) Weld heat from butt welds in strips may be weakening the bond local to the butt. The weakened area serves *as* a separation initiation point which may grow depending upon local stresses.

(b) Material properties may vary enough that some bond areas are susceptible to separation. This variation is not detectable by test methods required by MIL-J-24445.

(c) Strip widths may not be sufficient to meet manufacturers recommendations and to compensate for (a) and (b) above.

(d) Welding methodology, such as using shielded arc welding, could cause overheating and bond weakening.

The study showed that trimetallic transition joints greatly improve the reliability while offering potentially lower overall costs.

TABLE X
EFFECT OF CUTTING METHOD
ON BOND STRENGTH

BIMETALLIC

SEQ NUM	CUT BY	ULT STRESS	SEQ NUM	CUT BY	ULT STRESS
37	SAW	14,773	56	PLASMA	19,341
39	SAW	14,429	57	PLASMA	19,736
48	SAW	15,012	59	PLASMA	21,606
50	SAW	13,918	60	PLASMA	19,798
52	SAW	14,676	62	PLASMA	21,725
54	SAW	14,914	65	PLASMA	21,363
SUPPLIER=(DUPONT)			SUPPLIER=(EFI)		

SAW STATISTICS	PLASMA STATISTICS
AVG = 14,620	AVG =20,595
STD DEV= 364	STD DEV = 986
MIN99 = 13,771	MIN99 =18,297

TRIMETALLIC

SEQ NOM	CUT BY	ULT STRESS	SEQ NUM	CUT BY	ULT STRESS
78	SAW	20,991	66	PLASMA	22,119
79	SAW	23,400	69	PLASMA	26,006
83	SAW	26,041	70	PLASMA	21,594
84	SAW	22,744	71	PLASMA	26,544
87	SAW	29,077	72	PLASMA	28,201
			73	PLASMA	20,102
			74	PLASMA	20,192
			76	PLASMA	25,581
			77	PLASMA	26,799

SAW STATISTICS	PLASMA STATISTICS
AVG = 24,451	AVG =24,127
STD DEV= 2,826	STD DEV = 2,932
MIN99 = 17,867	MIN99 =17,296
SUPPLIER = (EFI)	SUPPLIER = (EFI)

RECOMMENDATIONS

MIL-J-24445

The government may want to revise this document to reflect current technology

(trimetallic), sampling from the weak areas of the plate (the initiation point) and incorporating statistical requirements for properties (MIN99).

DESIGN

Statistical knowledge of actual strengths of welded transition joint and structural plating should be considered. in establishing design guidelines. If a 1% disbond rate is considered acceptable, the recommendation based on data reported in this paper would be to provide bimetallic strip widths of 4.24 times the thickness of the aluminum plating. Minimum widths of the trimetallic material would be on the order of 3 to 1. These recommendations may be modified to take into account the width of weld fillets and needed reliability at strip butts.

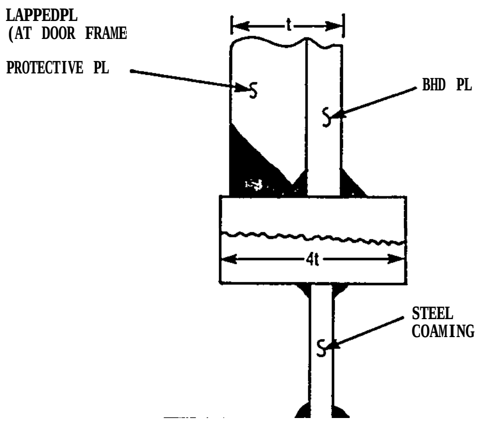
The designer should always specify a partial penetration butt design (as shown in Figure 4) and should give preference to designs which minimize butt welds. See Figure 7 for some ideas.

PRODUCTION

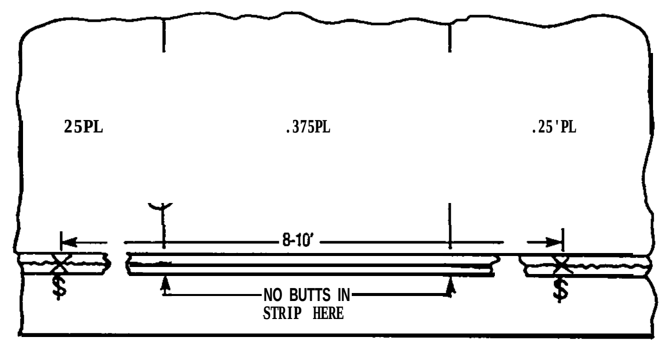
The peak bond joint temperature of bimetallic transition joints should be limited to 31 C (600°F) This *can* be done in production by prohibiting SMAW welding (tacking is OK) and limiting the interpass temperature tO a maximum of 204°C (400°F). Colder weld processes (short arc & pulsed arc) are slightly preferred over the more normal (spray arc) GMAW and FCAW processes, but all are acceptable. Care should be exercised to ensure full penetration butt joint designs are not substituted for partial penetration butt designs in the strips. The number and proximity of butt welds should be minimized. When plasma cutting, the highest feasible travel speed should be used. Submerging the transition joint plate in a water table may be beneficial to bond strength and to minimize thermal distortion of the strips. Periodic tensile and bend testing of plasma cut strips would be a wise precaution. Samples should be cut near the initiation point, if that is known.

SUMMARY

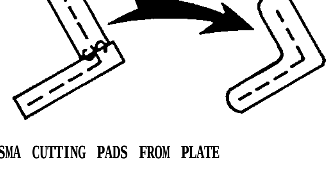
Some aluminum to steel bimetallic transition joints were disbonding in ships under construction and, to a lesser extent, in the fleet. This was unusual because the strips were designed to be stronger that the aluminum plating



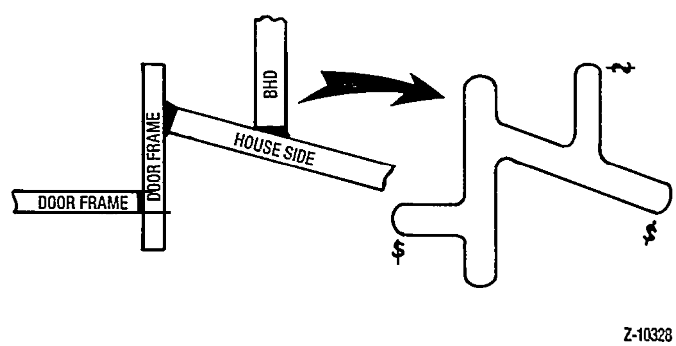
1. WHERE PLATE HAS LAPPED PLATE DESIGN STRIP WIDTH SHOULD CONSIDER TOTAL THICKNESS



2 MINIMIZE BUTTS USE FULL LENGTH STRIPS (8-10 TYP) WITH WIDTHS SIZED TO THICKER PLATING



3 SIMPLIFY BY PLASMA CUTTING PADS FROM PLATE



4. SIMPLIFY BY CUTTING COMPLEX INTERSECTION WITH PLASMA

Figure 7. Some designer recommendations

attached. A study was undertaken to determine the causes and recommend corrective measures. Several possible causes were found, some eliminated, and preventative measures instituted. The most significant improvements were in design and materials. During the course of the study, a new trimetallic aluminum to steel transition joint was introduced and certified. The trimetallic design provides higher strength and higher resistance to degradation during installation while offering potentially lower overall costs.

ACKNOWLEDGEMENT

The author would like to thank the following people for their contributions to this paper through helpful discussions:
Ivu Fioriiti, Retired
Milt Scaturro, NAVSHIPWEAPSYSENGSTA
Niles F. Bailey, Detaclad Operations
Lee Kvidahl, Ingalls Shipbuilding
Bob Stallone, Ingalls Shipbuilding
Bob Fargo, Ingalls Shipbuilding
Howard Bunch, Univ. of Michigan

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APPENDIX A
ISD TENSILE TESTS

SEQ NUM	REST-RAINT	WIDTH	LENGTH	ULT LOAD	ULT STRESS	INTERPASS MAX TEMP	HULL MATL	FAIL AT
5	R	1.255	3.333	34300	8200	150`F	CG53	AL-STL+WELD
10	R	1.003	3.180	41000	12855	150`F	CG53	AL-STL
13	U	0.991	3.297	50900	15578	150`F	CG53	AL-STL
14	R	0.990	3.367	45300	13590	150`F	CG53	AL-STL
15	U	1.001	3.330	56200	16860	150`F	CG53	AL-STL
16	R	0.989	3.280	45300	13965	150`F	CG53	AL-STL
17	U	1.001	3.331	52600	15775	150`F	CG53	AL-STL
18	R	0.989	3.313	52700	16084	150`F	CG53	AL-STL+WELD
19	R	0.987	3.356	52600	15880	150`F	CG53	AL-STL
20	U	1.009	3.372	56200	16518	150`F	CG53	AL-STL
21	R	0.989	3.279	52700	16251	150`F	CG53	AL-STL
22	U	0.991	3.256	51400	15930	150`F	CG53	AL-STL
23	R	1.003	3.361	54900	16286	150`F	CG53	AL-STL
24	U	0.987	3.304	52000	15946	150`F	CG53	AL-STL
25	U	0.990	3.380	54500	16287	150`F	CG53	AL-STL
26	RW	0.990	3.350	52800	15920	150`F	CG53	AL-STL
27	uw	0.994	3.276	49700	15263	150`F	CG53	AL-STL
28	R	0.988	3.214	51200	16124	150`F	CG53	AL-STL
29	uw	0.978	3.270	45400	14196	150`F	CG53	AL-STL
30	RW	0.984	3.336	54100	16481	150`F	CG53	AL-STL
31	U	0.989	3.267	51500	15939	150`F	CG53	AL-STL
32	R	0.995	3.325	55100	16655	150`F	CG53	AL-STL
33	uw	0.987	3.240	51800	16198	150`F	CG53	AL-STL
34	RW	0.984	3.256	51800	16168	150`F	CG53	AL-STL
35	uw	0.987	3.268	54000	16742	150`F	CG53	AL-STL
36	RW	0.998	3.300	53100	16123	150`F	CG53	AL-STL
37	U	0.997	3.191	47000	14773	400`F	CG65	AL-STL
38	R	0.992	3.231	46500	14508	400`F	CG65	AL-STL
39	U	0.994	3.291	47200	14429	400`F	CG65	AL-STL
40	R	0.993	3.275	46400	14268	400`F	CG65	AL-STL
41	R	0.989	3.284	45400	13978	400`F	CG65	AL-STL
42	U	0.976	3.334	51300	15765	400`F	CG53	AL-STL
43	R	0.990	3.207	46600	14677	400`F	CG53	AL-STL
44	U	0.976	3.267	48400	15179	400`F	CG53	AL-STL
45	U	0.982	3.291	44000	13615	400`F	CG53	AL-STL
46	R	0.991	3.289	39300	12057	400`F	CG53	AL-STL
47	R	0.988	3.287	48300	14873	400`F	CG53	AL-STL
48	U	1.002	3.304	49700	15012	400`F	CG65	AL-STL
49	R	0.987	3.244	45900	14336	400`F	CG65	AL-STL
50	U	0.993	3.285	45400	13918	400`F	CG65	AL-STL
51	R	0.981	3.350	46500	14149	400`F	CG65	AL-STL
52	U	0.994	3.311	48300	14676	400`F	CG65	AL-STL
53	R	0.993	3.241	46000	14293	400`F	CG65	AL-STL
54	U	0.998	3.225	48000	14914	400`F	CG65	AL-STL
56	U	1.179	3.346	76300	19341	PLASMA CUT	TEST	AL-STL
57	U	1.177	3.289	76400	19736	PLASMA CUT	TEST	AL-STL
59	U	1.172	3.333	84400	21606	PLASMA CUT	TEST	AL-STL
60	U	1.175	3.267	76000	19798	PLASMA CUT	TEST	AL-STL
62	U	1.170	3.344	85000	21725	PLASMA CUT	TEST	AL-STL
65	U	1.171	3.118	78000	21363	PLASMA CUT	TEST	AL-STL
66	U	1.118	3.417	84500	22119	TRI/PLASMA	TEST	TI-ST
69	U	1.150	3.210	96000	26006	TRI/PLASMA	TEST	ALL AL
70	UN	1.250	2.145	57900	21594	TRI/PLASMA	TEST	TI-ST
71	U	1.152	3.231	98800	26544	TRI/PLASMA	TEST	1100 AL
72	U	1.150	3.438	111500	28201	TRI/PLASMA	TEST	1100 AL
73	UN	1.134	2.812	64100	20102	TRI/PLASMA	TEST	1100 AL
74	UN	1.290	2.361	61500	20192	TRI/PLASMA	TEST	1100 AL
76	U	1.160	3.370	100000	25581	TRI/PLASMA	TEST	TI-ST
77	U	1.120	3.265	98000	26799	TRI/PLASMA	TEST	1100-5456
78	UN	1.190	2.450	61200	20991	TRI/SAW	TEST	1100-5456
79	UN	1.175	2.375	65300	23400	TRI/SAW	TEST	1100-5456
83	UN	1.255	1.995	65200	26041	TRI/SAW	CG72	ALL AL
84	UN	1.248	2.142	60800	22744	TRI/SAW	CG72	1100 AL
87	UN	1.257	1.855	67800	29077	TRI/SAW	CG72	1100 AL

APPENDIX B
EFI TRIMETALLIC FIRST ARTICLE TESTING

TEST TYPE	PRE-HEAT PEAK/HOLD	BOND ZONE TESTED	SAMPLE FROM *	REQUIRED RESULT	ACTUAL RESULT	REQD. BY MIL SPEC,
TENSILE	NONE	ALL	IE	11,000	26,847	Y
"	NONE	ALL	TE	11,000	31,685	Y
"	600 DEG	ALL	IE	11,000	24,941	Y
"	600 DEG	ALL	TE	11,000	21,339	Y
"	1000 DEG	ALL	IE	11,000	20,660	N
"	1000 DEG	ALL	TE	11,000	21,371	N
SHEAR	NONE	AL-TI	IE	8,000	14,687	Y
"	NONE	AL-TI	IE	8,000	15,448	Y
"	NONE	AL-TI	IE	8,000	15,939	Y
"	NONE	AL-TI	TE	8,000	16,681	Y
"	NONE	AL-TI	TE	8,000	16,292	Y
"	NONE	AL-TI	TE	8,000	16,411	Y
"	NONE	TI-ST	IE	8,000	40,523	
"	NONE	TI-ST	IE	8,000	45,737	f
"	NONE	TI-ST	IE	8,000	43,001	Y
"	NONE	TI-ST	TE	8,000	42,870	Y
"	NONE	TI-ST	TE	8,000	47,350	Y
"	NONE	TI-ST	TE	8,000	46,079	Y
"	600 DEG	AL-TI	IE	8,000	16,630	Y
"	600 DEG	AL-TI	IE	8,000	14,292	Y
"	600 DEG	AL-TI	IE	8,000	14,650	Y
"	600 DEG	AL-TI	TE	8,000	15,104	Y
"	600 DEG	AL-TI	TE	8,000	14,552	Y
"	600 DEG	AL-T-I	TE	8,000	14,292	Y
"	600 DEG	TI-ST	IE	8,000	42,361	Y
"	600 DEG	TI-ST	IE	8,000	37,786	Y
"	600 DEG	TI-ST	IE	8,000	43,324	Y
"	600 DEG	TI-ST	TE	8,000	47,317	Y
"	600 DEG	TI-ST	TE	8,000	51,874	Y
"	600 DEG	TI-ST	TE	8,000	50,391	Y
".	1000 DEG	AL-TI	IE	8,000	16,505	N
"	1000 DEG	AL-TI	IE	8,000	14,732	N
"	1000 DEG	AL-TI	IE	8,000	15,618	N
"	1000 DEG	AL-TI	TE	8,000	18,062	N
"	1000 DEG	AL-TI	TE	8,000	19,318	N
"	1000 DEG	AL-TI	TE	8,000	17,726	N
"	1000 DEG	TI-ST	IE	8,000	39,144	N
"	1000 DEG	TI-ST	IE	8,000	39,359	N
"	1000 DEG	TI-ST	IE	8,000	40,829	N
"	1000 DEG	TI-ST	TE	8,000	39,144	N
"	1000 DEG	TI-ST	TE	8,000	39,359	N
"	1000 DEG	TI-ST	TE	8,000	40,829	N
WELDED TENS	NONE	ALL	MIDDLE	23,000	26,100	Y
"	NONE	ALL	MIDDLE	23,000	25,000	Y
FATIGUE			MIDDLE			
-15/+5,150KC	NONE	ALL	MIDDLE	PASS	PASS	Y
-15/+1,650KC	NONE	ALL	MIDDLE	PASS	PASS	Y
-10/+3,1MC	NONE	ALL	MIDDLE	PASS	PASS	Y
SIDE BEND	NON-E	ALL	IE	PASS	PASS	Y
"	NONE	ALL	TE	PASS	PASS	Y
"	600 DEG	ALL	IE	PASS	PASS	N
"	600 DEG	ALL	TE	PASS	PASS	N
"	1000 DEG	ALL	IE	PASS	PASS	N
"	1000 DEG	ALL	TE	PASS	PASS	N
CHISEL	NONE	ALL	IE	PASS	PASS	Y
"	NONE	ALL	TE	PASS	PASS	Y
"	600 DEG	ALL	IE	PASS	PASS	N
"	600 DEG	ALL	TE	PASS	PASS	N
"	1000 DEG	ALL	IE	PASS	PASS	N
"	1000 DEG	ALL	TE	PASS	PASS	N

* IE IS INITIATION POINT END, TE IS OPPOSITE (TRAILING) END

Ivo Fioriti, PE, Retired from NAVSEA

I have read your paper with a degree of sadness because you discuss problems which should not have been and did not occur while I was in charge of the development throughout the late 60's and all of the 70's. The people involved with the development then are long gone. If there are problems, the new breed of engineers that replaced them may not have maintained the same high quality levels necessary in manufacture and fabrication to avoid bond separations. I remain confident that the problems can be solved once the underlying causes of bond separations become known.

Selling a new, radical concept for shipbuilding, particularly Navy, is a very difficult task indeed. So it was with the transition joint material. Therefore, the participants were very careful in their role during the development. The Navy subjected the transition joint material to severe testing (beyond service performance needs) like explosion bulge testing, structural beam fatigue to very high stresses, thermal fatigue, corrosion and the many small scale mechanical tests. At no time did bond separation become a problem. This work was done on the Dupont detaclad joint and the Revere Copper & Brass roll bonded joint. For all follow on producers of the transition joint material, the qualification tests were reduced to the small scale mechanical tests. Northwest Technical qualified later on the basis of small scale mechanical tests a short time before I retired from Navy. Explosive Fabricators {qualified after I left}. The secrets of the successful development, in short, were three fold: (1) The Navy's tortuous qualification testing of the transition joint. (2) The manufacturer's production knowledge of what was well bonded material and what was not. Through an in-house NDT (which was correlated with mechanical bond strength tests), the manufacturer knew what was good and bad, and only sold good transition joint material to Navy and shipbuilders. (3) The shipbuilders were well aware of the effects of welding heat degradation of the joint material and instituted well supervised safeguards to avoid surpassing the 600°F limit.

The MIL-J-24445 specification is not a sacred cow! After my retirement from NAVSEA, there were people at NAVSEA revising the specification who had no experience with the transition joint material. Also, because the specification covers explosive bonded, roll bonded and any other new procedure than can qualify, it cannot institute a NDT bond procedure across the board that applies equally well to all the joint materials. Therefore, the in-house NDT technique that Dupont or Revere Copper & Brass used to furnish well bonded material never got into the specification as a detailed requirement. However, the bonding and quality control procedures, and materials used by the manufacturer in obtaining qualification became a requirement of the Navy approval letter. The letter states that the manufacturer shall use the same procedures/materials that were approved for the production of material to be offered under the Mil. Spec.. Any changes to those procedures are subject to Navy approval and may be the subject of re-qualification. Therefore, it is not correct to say the transition strip must only meet the Mil. Spec.. At this late date, it would be interesting to compare a manufacturer's present procedures/materials with those that were used way back then to obtain qualification approval. If poorly bonded material is being received in the shipyard, the first thing would be to review the responsible manufacturer's production procedures/materials, and second review the Mil. Spec. for weaknesses and improvements to alleviate the problem. As part of this same study, all of the Mil. Spec. revisions issued from the first to the present should be reviewed to document technical requirements and changes to determine if the specification was strengthened or weakened over the years. Your paper does not address these items and they are at the heart of any bond separations.

What you have found out about UT inspection was well known 20 years ago at the start of the program. UT inspection in the specification can only provide protection against poorly bonded material that is on the verge of forming a lamination. That is why the Dupont in-house NDT quality control procedure was not based on UT.

Documentation of all bond failures in detail is essential by the shipbuilders and Navy so that the cause(s) can be determined and rectified. If the bond failures can not be solved, then there is a problem. However, most likely, the cause becomes known and there is no good reason to fault the transition strip material. Your paper does not go into this and you are trying to find a cause for the bond separations.

All of the bonded material you welded and tested should have received a valid NDT quality control procedure (like DuPont's in-house control) before hand. In this manner you may have been able to explain some of your results, especially as to variations in terms of bond quality.

In reviewing all of your tensile test

data in the tables, I haven't found any values that do not meet the Mil. Spec. minimum tensile strength requirement of 11,000 PSI. Therefore, the tensile data do not prove you have a bond strength problem. In fact, in Table IV with a maximum interpass temperature of 400°F, the data still meets the requirement. Each table should show the Mil Spec. requirement. It is very important to include the above tensile test data findings as a conclusion in your paper.

On strip widths, your analysis is academic using the wrong numbers. The 4 to 1 design rule is more than adequate and conservative. Also, you need a proper landing area for the aluminum fillet welds and a little lee way on fit-up where the deckhouse plating does not land in the exact center of the transition strip. This area need is also required for the trimetallic strip.

On restraint, you do not show the restraining fixture and you have not measured residual stresses. Nor do you know what the variation in bond quality (meaningful NDT method) is. The two groups of data look very good! Normally, in welding configurations of this type, you would not expect restraint to be a factor because of the thin plating thicknesses. small fillet welds and the low yield strength of the 1100 aluminum alloy. Note, I said "yield strength" and you said "tensile strength".

There is not enough time and ships represented to make much of the data in Table VIII. Studies of this type should continue into the future as more ships are built. All the numbers look good, well within Mil. Spec. and probably are comparable to the old material of the 70's.

The trimetallic development is significant where improved bond strength is needed. But your paper does not prove that greater bond strength is needed. So why do you want to go to a more expensive material? Note the high speed plasma cutting (which can save money) in Table X can also be made to apply to the bimetallic and results in a substantial improvement in bond strength. The improved elevated temperature performance of the trimetal does not necessarily translate into thinner transition strips. In going to thinner steel and aluminum, other problems begin to arise like distortion/flatness tolerances of the material prior to bonding and distortion of the thinner strips during fabrication in the shipyard (higher temperatures + thin material = distortion). Also, the 20% price increase for the trimetal, most likely, is a foot in the door price. It would not surprise me if the actual increase becomes 30 to 40%. Finally, I would expect the Navy to permit use of both the bimetal and trimetal strips on an equal basis in the Ship Design Specifications. In the end, it will be the shipbuilder who decides what to use and cost will control.

On the trimetal qualification for ship service I would say that MIL-J-24445 is not entirely adequate. The addition of titanium in the sandwich introduces a material that is more noble in the electro-motive series than steel and aluminum. Therefore, the concern for corrosion becomes greater. MIL-J-24445 was intended only for steel/aluminum joint strips, which were proven satisfactory in corrosion tests during development. The corrosion tests were not considered necessary in the MIL-SPEC for qualification, as long as the materials were steel and aluminum. Recommend corrosion tests be performed on bare surface and painted surface specimens: (1)salt air, (2) salt air fog, (3) salt water spray and (4) intermittent salt water immersion (heavy seas/main deck awash).

Your designer recommendations in figure 7 were recommended in papers/literature prior to first use of detaclad. If a shipbuilder has not been following your recommendations from day one, its his own fault.

In Appendix A, the failure location is not clear. Suggest you use a cross section of the complete joint showing the various fracture paths. If you got bond failures, this is something different from the early work.

For your information, I would like to mention the good points of the Revere roll bonded bimetal. The Revere bimetal exhibited (over detaclad {bimetallic)) slightly higher fatigue strengths in large scale structural beam tests, showed a greater tolerance for the heat of welding and was responsible for the reduction in thickness of the Dupont bimetal from 1 3/8" to 3/4", has the potential of producing longer strips to reduce the number of butt joints, the potential of being made in thinner thicknesses, and the potential for a more uniform quality level by closer control of manufacturing variables. After development, the shipbuilders were at fault for not accepting the roll bonded bimetal as an equal to the detaclad. Detaclad was specified on the drawings and ship specifications and it would have cost money to change them. They had worked out fabrication procedures for detaclad and would have to do the same for roll bonded. Running scared on such an important joint, many simply did not trust the roll bonded material. So Revere never got enough business to get out of the pilot plant stage. The shipbuilders and the Navy in the long run-were the real losers: The competition would have been good for improve-

ments, quality and cost savings.

If you have any questions on what I have written, I suggest you get in touch with Chuck McKenny (who is now a consultant), Allen Manuel NAVSEA55Y3 for the old files if he still has them, and Revere Copper & Brass- Rome N.Y. office.

Lots of luck to you!

Sincerely,
Ivo Fioriti

Attachment 2

Discussion by Ivo Fioriti, PE, 2932 Fairhill Rd., Fairfax, VA 22031 (703) 560-2357 dated 30 April, 1990

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24,199O

What Can Adhesives Offer to Shipbuilding?

6A-1

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ABSTRACT

This paper presents an overview of recent research into the feasibility and advantages of using toughened structural adhesives to replace some conventional welding for primary structures in the shipbuilding and associated marine industries.

The concept is explored through its application to the stiffener/plate connections of thin plated grillage structures where a number of advantages can be identified. These include the potential for elimination of thermal distortion and residual stress with little cost or weight penalty. Data is becoming available on such longer term problems as durability in the marine environment, high temperature performance (including creep), fatigue and impact resistance. Research is continuing to improve understanding and increase confidence in application to large scale structures.

The paper concludes that the benefits to be gained from using adhesives to achieve novel structural configurations, possibly involving dissimilar materials, will provide continuing impetus to research and development in this area.

1. INTRODUCTION

The question in the title was first posed about six years ago when compiling the list of final year undergraduate student projects within the Department of Naval Architecture and Ocean Engineering at the University of Glasgow. At that time there had been a considerable amount of research and development effort expended in the civil engineering sector [1] advancing the use of structural adhesives as a means of adding additional stiffening members or extra flange material to the girders of bridge structures within the UK. As these applications appeared to be generally successful, it seemed that there was scope to apply similar technology within the construction of both ships and fixed or floating offshore structures.

An early potential application emerged in the grillage structure of frigates being built for the British Navy (MoD(N)). The shipyards involved have long experienced difficulty in controlling the distortion induced by the welding of the small section 'Admiralty Tees' to shell, deck and bulkhead plating. In general, the problem stems from the excessive size of the double fillet weld beads used for their attachment to relatively thin plating (typically Smm) where intermittent or staggered welding would have been sufficient for strength, but not acceptable to the MoD(N). Adhesive joints would appear to offer a practical solution to the shrinkage and distortion problems so often encountered in such light plated structures.

As a first step, a student project [2] investigated a number of possible adhesives and their application to bonding short sections of beam elements. typical of the warship structures referred to above, using 'I' beams in place of Tee sections. Although limited in its objectives, this project demonstrated both the smooth, unstressed nature of the bonded specimen and the feasibility of loading such beam elements in three point bending until the web of the stiffening member suffered plastic collapse without any signs of failure of the bond line between plate and stiffener. Figure 1 shows such an early museum piece, as it survives to this day in a heavily deformed state without showing any tendency to fail by creep or ageing.

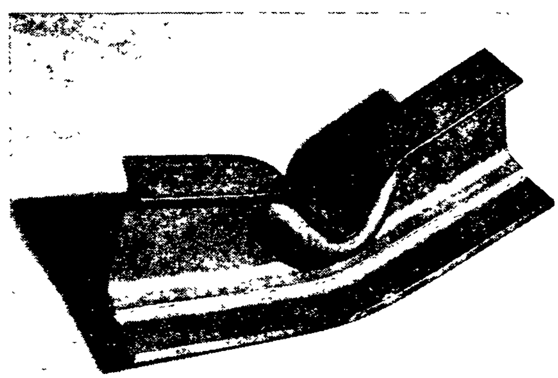


Figure 1 Early test specimen after six years

This early success inspired a two year programme of research to survey available adhesives, develop methods of fabrication and determine the material and structural properties of bonded stiffener to plate connections in lightweight ship grillages. The results of this programme [3] are summarised in Section 2. as the basis from which to introduce the findings of a number of more recent related projects, discussed in Section 3.

From these test programmes it is now clear that adhesives offer an alternative joining technology which may have important implications for significant parts of the structural design and fabrication of various ship and offshore structures. In particular this technology opens up the twin

possibilities of lightweight sandwich construction and the combination of a wide variety of dissimilar materials to achieve specific design objectives. However, before this can be achieved the designer must understand the strengths and the weaknesses of both adhesives and bonding process, working to the former and eliminating the latter, so far as possible. A major objective of this paper is to contribute to this understanding.

1.1 Engineering Applications of Adhesives

At first sight the engineering properties of adhesives appear to offer little to the designer: viz. low strength, very dependent on temperature; low modulus; brittle. However, from modest beginnings in the 1940's. adhesives are now widely exploited in the aerospace industries and thereby provide a very important general basis for extrapolation into new fields through the availability of long term service performance. The successful bonding of aluminium alloys in this sector of industry also demonstrates some of the problems often considered to be inherent in the use of adhesives in general, i.e. the importance of careful surface preparation and the need for sophisticated jigs, fixtures and autoclaves to achieve a satisfactorily cured joint. It should be remembered, however, that the development of a range of toughened epoxy and acrylic adhesives in the 1970's has also catalysed a large number of applications in the automotive and general engineering sectors applied principally to the bonding of aluminium alloys as well as steel [4. 5, 6. 7, 8, 9]. An important stimulus to this trend seems to be that the fabrication and preparation requirements are in general far less stringent for steel than aluminium alloys (where careful growth and preparation of a stable oxide layer is required) while steel/steel bonding offers the highest potential for joint strength [IO].

It is not surprising therefore that several applications have already been found for adhesives in the marine industries. These range from the temporary repair of fatigue cracks in the superstructures of warships [11] to the longer term repair of damage to the tubular members of offshore jacket structures through the application of bonded sleeves [12]. Although many of these applications started as short term emergency measures, the benefits have proved so attractive that the owners of a well known passenger ship have modified the superstructure in way of structural openings by incorporating bonded doublers. In addition, several examples of the use of relatively low strength adhesives have appeared in Russia [13] involved in the manufacture of lightly loaded bulkheads, fire and watertight doors, instrument casings and ventilation ducts.

1.2 Adhesive Selection

Modem adhesives can be divided into two classes [14]:

thermosets - which set by chemical reaction

thermoplastics - which set as the result of physical changes such as solvent evaporation or solidification.

Both classes are important industrially but generally only the thermosets are able to withstand sustained loading. However, some recently developed hot melt thermoplastic resins such as polyetheretherketon (PEEK) could prove superior to the more widely used thermosets, they are extremely expensive at present and difficult to use when bonding large structural components [15, 16].

Among the therrnosets are two resin groups which stand out as having potential for bonding structural steel - epoxy and acrylic. Recent developments [17] have led to the introduction of toughened formulations in both these groups through the inclusion of a dispersed rigid or rubbery phase in the resin matrix which substantially increases resistance to crack propagation by absorption of energy at the crack tip. In consequence the onset of catastrophic adhesive failure is delayed and the resistance of a joint to cleavage and impact forces can be markedly improved. Toughening has not so far been successfully applied to other types of structural adhesives [18].

Toughened acrylic adhesives are generally rapid curing and give high cleavage and impact resistance. They are supplied in two parts (resin and catalyst) which usually require premixing in specialised dispensing equipment to achieve best results. They often contain volatile, flammable monomers and so vapour extraction is important for large structural applications. Acrylic adhesives are generally more suitable for joining plastics and have yet to be established as suitable for metals subject to high humidity and/or elevated temperature. In terms of both strength and stiffness, toughened epoxy adhesives are generally superior to acrylics for metal assemblies and also possess better heat, creep and environmental resistance.

Through their superior performance, toughened epoxies appear to offer the most suitable candidates for bonding structural steel. They are generally available in either one-part (hot cure) paste/film or two-part (cold/warm cure) paste. The hot cure varieties are essentially a premixed version of the two-part having exceptionally long cure times at room temperature. The hot (or warm) cure tends to improve the wetting of the adherend and encourage the development of strong molecular cross linking in these adhesives, thereby imparting better room temperature strength while allowing substantial time for adjustment of one or more joints prior to cure. Strength at, and resistance to, elevated temperature exposure is also improved through the higher glass transition temperature of the hot cured adhesives. This is likely to be important in any environment (such as shipyards) where the local damage effects of welding and gas cutting are to be expected.

The formation of an adhesive bond may be explained in terms of the intermolecular forces which cross link the adhesive and adherends. The development of a durable bond depends on intimate contact. Intimate, continuous contact is difficult to achieve if either surface is contaminated with oil, dust, corrosion products or release agents; so efficient removal of these contaminants is generally essential. Such surface preparation usually requires solvent degreasing followed by abrasion or grit blasting and a final solvent wash to remove any remaining surface debris. However, one of the more notable features of the toughened

adhesives is their good wetting properties which allow them to absorb thin oil films and dust particles. In general therefore, although *some* care is required, the surface preparation requirements for the structural epoxies used in the current programme are far less stringent than those applying to aluminium and its alloys as applied in the aerospace industries. In addition, the application of a water-based silane primer to both adherend surfaces should provide both a useful indicator of surface contamination and an ideal molecular link between steel and epoxy. The chemist argue that this should greatly improve the long-term durability of such joints in wet conditions.

Although film adhesives have worked well in small scale experiments they do not appear to offer sufficient initial thickness or viscosity to accommodate the inevitable variations in bond line thickness with stiff adherends. Paste adhesives, on the other hand, are easy to handle, being dispensed from hand or power operated guns as a uniform bead onto one of the adherend surfaces. Through the use of various modifying agents the viscosity of the adhesives can be adjusted by the manufacturers to cope with varying joint gaps (up to 2mm) as well as application to vertical surfaces without risk of loss of adhesive during cure. The structure must be clamped while the adhesive cures - with epoxy pastes only limited pressure is required for this process. . Any resulting spew fillet is best left undisturbed as it extends the bond area and reduces the stress concentration at the edge of the joint while improving the seal. Once cured the adhesive is generally assumed to retain its properties permanently.

1.3 Fabrication Procedure

At an early stage, a laboratory prototype system for heat curing stiffened panels had to be developed which would be capable of later development for full scale shipyard production. This is illustrated in Figures 2 and 3. Modelled on the stiffener injection and welding stages of a conventional automated or semi-automated panel line, the concept relies on sets of electrical resistance heating elements aligned with the joints on the underside of the plating. In full scale production it is anticipated that a number of rows of these elements could be supported on mobile. pressurised supports to be aligned with the joints, forming the base of the clamping jig which is necessary to support and align the stiffeners - in much the same manner as the one-side weld backing systems so common in the Japanese industry.

In normal conditions, the recommended cure cycle requires a steady rise in temperature to approximately 180°C over a period of about an hour. This peak temperature is held for about 30 minutes to effect the cure, before the assembly is allowed to cool naturally to room temperature. Temperature control is effected through a feedback controller with one or more thermocouples attached to the bond line. While it is appreciated that this is a time consuming process. it can be safely automated and requires no human intervention. Thus it is an ideal off-shift activity which could be scheduled at night without interfering with the rest of the production process.

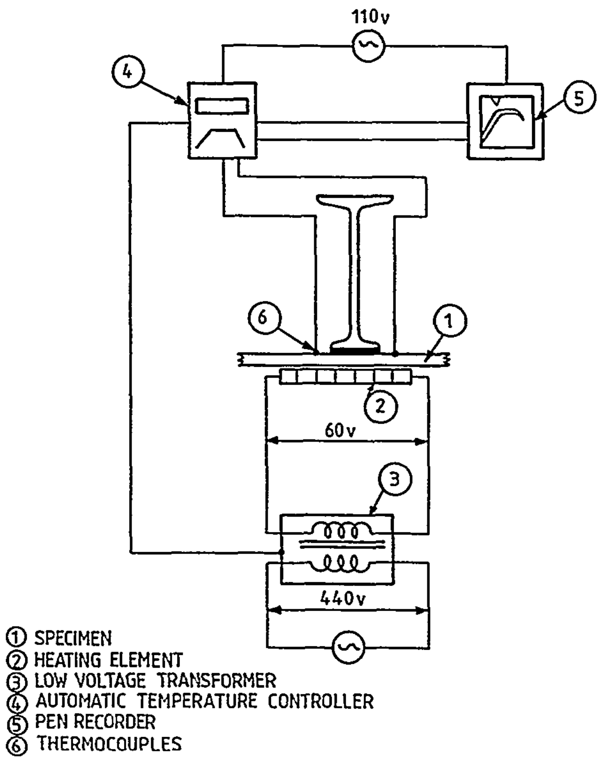


Figure 2 Schematic of heat curing process

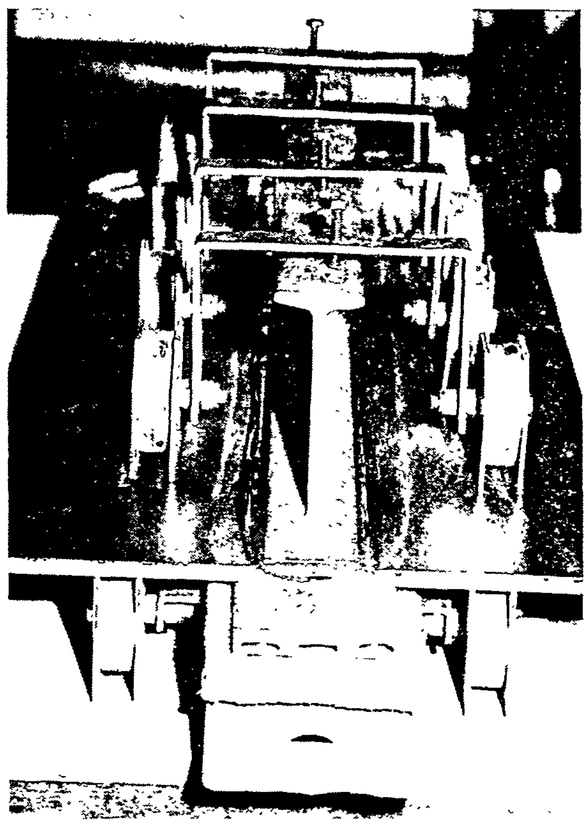


Figure 3 Layout of specimen during bonding

The minimum required preparation processes would consist of:

a. abrasion of the bond line surfaces to a surface roughness of 5-10um [19] using air powered flexible grinding equipment

b. brush or suction removal of debris

C. application of self-indicating silane primer to both surfaces

d. dispensing a uniform bead of adhesive paste to the stiffener flange

e. positioning and lightly clamping stiffeners to plate surface - simple magnetic bridges are adequate (see Figure 3). The use of adequate clamping is important to maintain a consistent minimum joint gap to avoid the formation of voids within the joint which are not easily rectified after curing.

It has yet to be determined whether an intermediate organic solvent degreasing stage is required between b. and c. for most large scale practical applications. In laboratory tests this stage has been retained to ensure optimum performance of test joints for comparison purposes. During these stages it is important that safety rules relating to skin protection, ventilation and flammability of solvents are observed.

2. EARLY EXPERIMENTAL PROGRAMME

The initial research programme concentrated on the problem of applying adhesives to the stiffener/plate connection of flat plate grillages as commonly found in the decks and bulkheads of ships. The choice of this joint was deliberate in that under bending load actions it is subjected primarily to bending shear along the line of the joint. However, as the joint is relatively close to the neutral axis of the plate/stiffener combination, the induced bending stresses are significantly less than the maximum stress in the stiffener flange. Thus the opportunity is available to use the adhesive in its strongest mode - that of shear - without exposing it to extreme loads.

Four aspects of the problem were apparent from the outset:

1. choice of adhesive through small scale standard tests

2. design of the joint to minimise risk of failure from end effects and secondary collapse mechanisms

3. verification of stages 1. and 2. through large scale panel bend tests

4. assessment of the impact performance of the joints

At the same time a number of longer term durability tests were established to allow this aspect of the problem to be monitored as the research programme developed. Details of these tests have already been published 120. 211 but are summarised below.

2.1 small Scale Standard Tests

One of the more important aspects of dealing with adhesives is coming to terms with the stress concentrations always present close to the boundaries of bonded joints [22]. These are illustrated in Figure 4 for the three basic modes of loading: tensile shear, symmetric axial tension and asymmetric axial tension (cleavage). It is evident that as these local stress concentrations determine the failure load. The nominal failure stresses (derived from load divided by area) are not therefore a reliable guide to the design strength of larger joints. In reality, most small scale standard tests are only useful for comparative rather than design purposes. It is also important to note from Figure 4b that the reliability of the tensile strength assumed for these adhesives is governed by the degree of cleavage which is present in the loading. The difficulty of eliminating this problem in small scale tests explains a measured variability of ±25 % among groups of three specimens in this type of test.

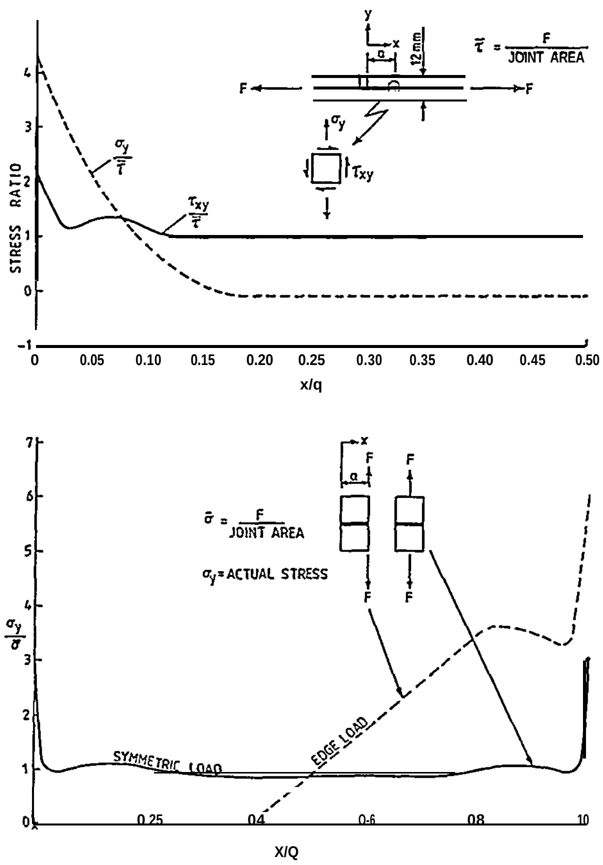


Figure 4 Typical stress distribution in adhesive joints

Figure 5 illustrates the range of ASTM and BS standard tests which were used to assess the relative merits of five paste and two film adhesives in a process of elimination to determine two candidate adhesives for larger scale testing and evaluation. The adherends were manufactured from mild steel stock (BS4360 Grade 43A) by milling and grinding to the dimensions indicated. Surfaces were prepared by solvent degreasing, grit blasting and further

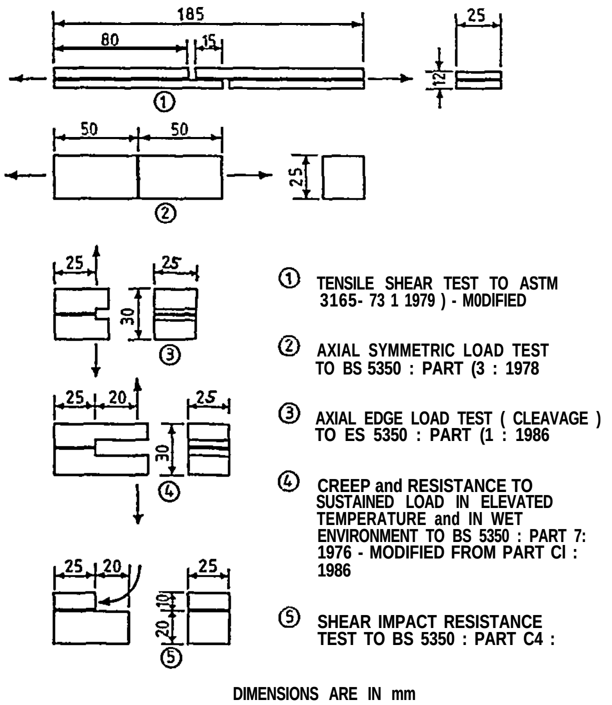


Figure 5 Standard test specimens

degreasing. The adhesives were all commercially available structural epoxies applied in nominal joint thicknesses of 0.15-0.2mm before curing to manufacturers recommendations. Progressive elimination based on the average results of three specimens for each test commenced with shear and cleavage tests followed by the tensile, shear impact and creep tests (under 50% ultimate load in salt water for 1000 hours). Three adhesives performed well in most of these tests, their results being summarised in Table I.

Both ESP110 (Permabond) and Araldite 2007 (Ciba Geigy) exhibit good all round static strength properties as well as shear impact and creep durability in sea water and therefore formed the basis of further testing. The significant difference between these adhesives is largely in their elastic modulus (manufacturers bulk figures) which has implications in the larger scale tests.

A range of further tests conducted using these two adhesives indicated that:

- joint thickness in the range 0.1-0.5 mm has no significant influence on joint strength except in the case of butt joints
- the presence of the a spew fillet can increase joint strength by up to 15% in many of these small specimens
- lightly contaminated surfaces have no short term effect on joint strength
- post cure cooling rate does not appear to affect joint strength
- prolonged post cure heating at 120°C for up to 20 hours does not affect joint strength.

2.2 Joint Design to Minimise Cleavage Effects

With the relative weakness of adhesive joints in cleavage it is important to give some considerations to the load actions which might produce this effect. One is the lateral instability of grillages under axial compression [22, 24] which can induce relative rotation between plate and stiffener about the axis of longitudinal joints. Resistance to this load action is provided by the width and stiffness of the lower stiffener flange (foot) which the designer would like to minimise. Another cleavage action is experienced at the free end of a stiffener joint - well known in the bonded stiffeners of large GRP hulls [25]. In this case it was thought that a tapered or shaped stiffener end might be beneficial through the introduction of a flexible toe to the stiffener to produce a gradual change in stiffness.

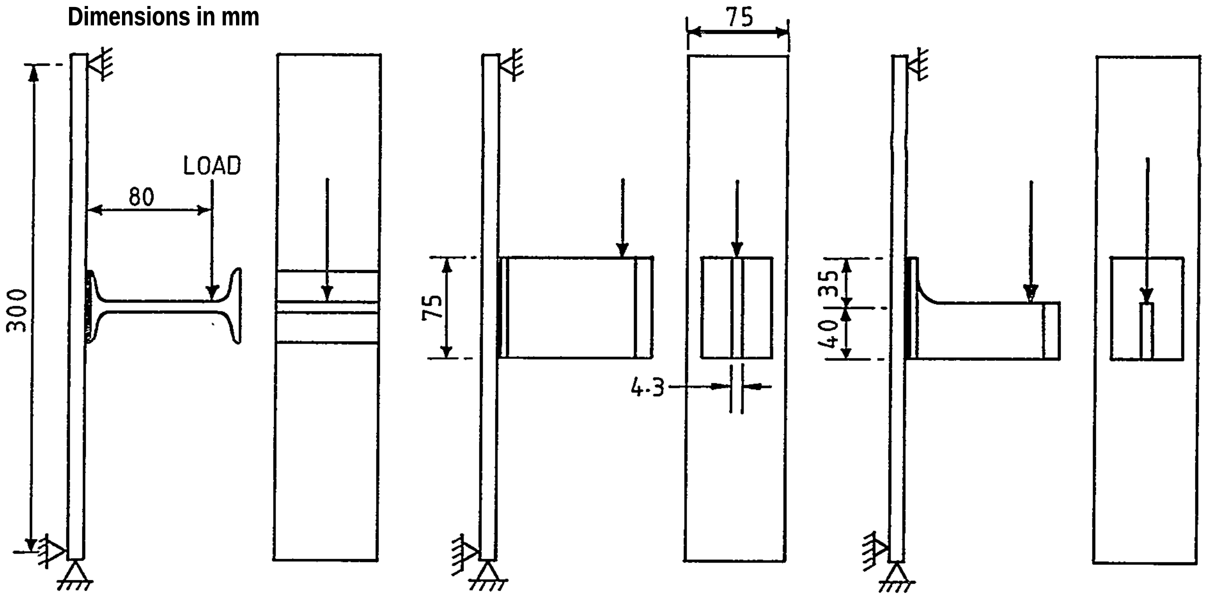
Figure 6 illustrates the general arrangement of this test series based on reduced 100mm deep 'I' sections bonded using Araldite 2007. Although these tests were somewhat qualitative in nature a number of important conclusions emerged:

- transversely loaded specimens of type 1 showed high resistance to cleavage with widths of 15 to 45 mm, all specimens failing by collapse of the stiffener web without bond failure. This indicates a potential for bonded structures to have bonded stiffener feet no larger in sectional area than the double fillet welds they replace
- variation of the thickness of the bonded flange between 2 and 6 mm did not affect the type 1 test results
- shaped stiffener ends (type 3) are up to 50% stronger than their square cut (type 2) counterparts
- end cleavage strength is proportional to base plate stiffness - joints sustained twice the load on 10mm plates compared to 6mm.

Figures 7 and 8 illustrate typical specimens from these tests which did not fail in the adhesive.

Table I - Comparative Properties of Adhesives Tested

Adhesive	Form	Cure Temp	Cure Time		Strength		Elastic Modulus	Impact Resistance
				Shear	Tensile	Cleavage		
		°C	min	N/mm^2	N/mm^2	N/mm^2	N/mm^2	J/cm^2
E5238	paste	190	30	40.4	51.4	15.2	2010	6.7
ESP110	paste	180	40	44.8	82.3	16.1	11250	8.4
Araldite 2007	paste	180	30	48.5	86.3	18.8	5230	8.5



① SIDE LOADED (TRIPPING) SPECIMEN ② CLEAVAGE LOADING SPECIMEN (SQUARE END) ③ CLEAVAGE LOADING SPECIMEN (SHAPED END)

Figure 6 Cleavage specimens

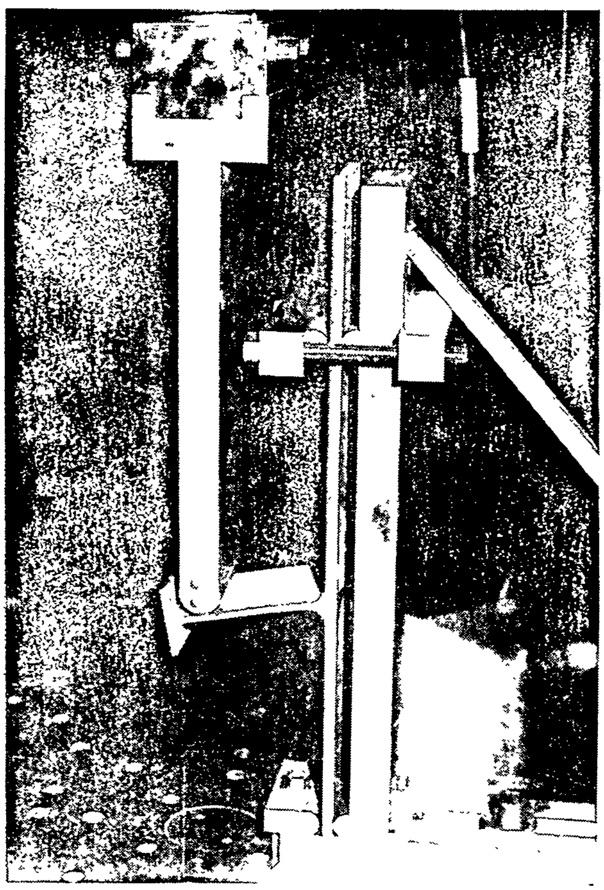


Figure 7 Side loading experiment

Figure 8 End cleavage experiment

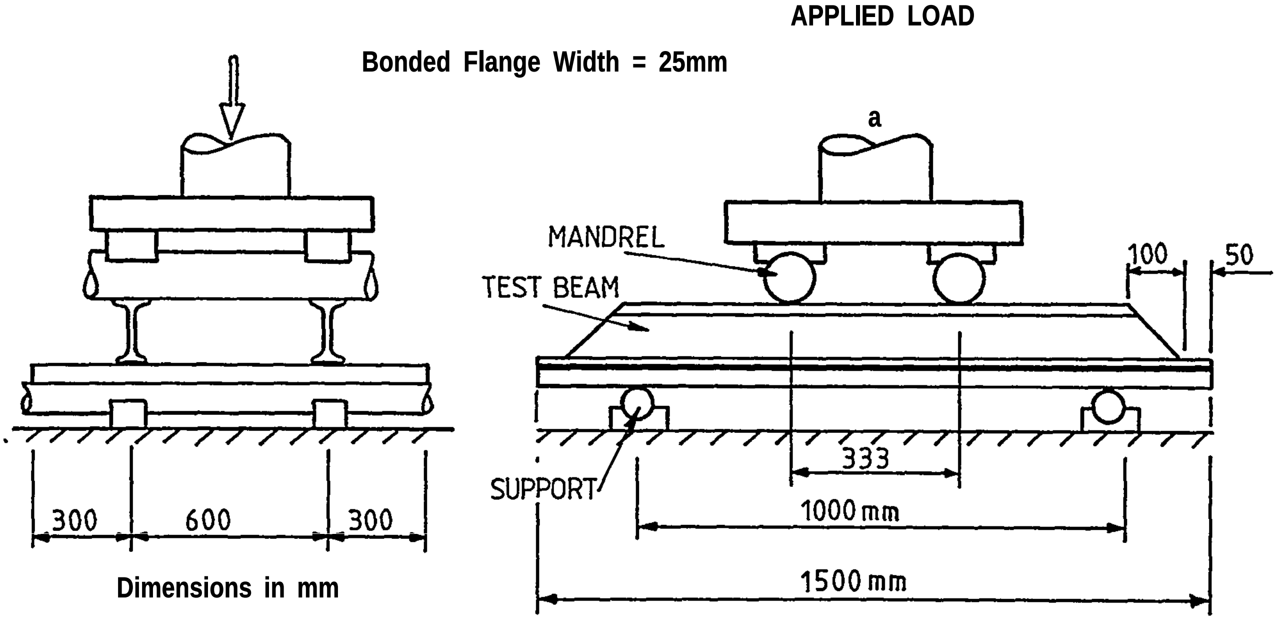


Figure 9 Four point bending test

2.3 Large Scale Panel Tests

To validate both the panel fabrication technique and the small scale tests outlined in 2.2 above, 1.5 x 1.2 m panels were fabricated, each carrying two 100 mm 'I' section stiffeners with reduced bonded flanges (25 x 2 mm) and tapered ends on 8mm plate, as shown in Figure 9. These were tested in four point bending over a span of 1.0 m, one from the stiffener side and the other from the plate side.

In each case central deflections of about 2.5% of span were achieved, by which time the stiffener web and flanges had collapsed as shown in Figure 10. At the elastic limit for these panels the maximum adhesive shear stress was estimated by composite beam theory to be about 28 N/mm^2.

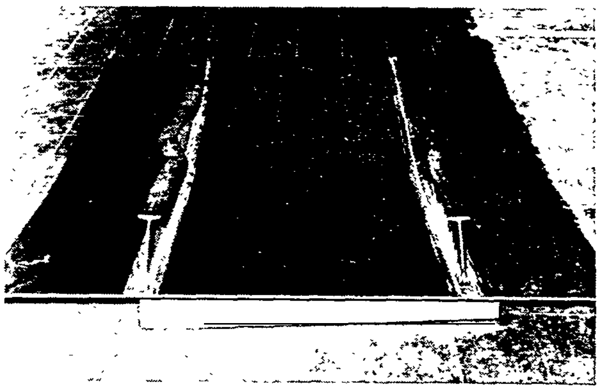


Figure 10 Large scale test panel showing buckled stiffeners

2.4 Impact Tests

The behaviour of a bonded joint during impact loading is not only governed by the relative weakness of adhesives to cleavage/tensile stresses [26], but also by the fact that polymers, unlike metals. have properties which are relatively independent of strain rate [27. 28]. It was therefore suspected that one of the limiting criteria for the widespread application of adhesives would be poor impact resistance.

In order to gain some assessment of the parameters affecting impact resistance, a number of smaller beam elements were assembled using the same materials as in the large scale panels. Three different stiffener end conditions were applied (as shown in Figure 11) in conjunction with two adhesives of differing modulus and with adhesive thickness less than a nominal 0.5 mm. Two additional specimens were included with nominal adhesive thickness of 1.5-2-0 mm to examine the effects of adhesive thickness. The specimens were tested in a drop weight tower and the energy absorbed in dropping a round nosed steel projectile of variable mass up to 6.4 kg from heights up to

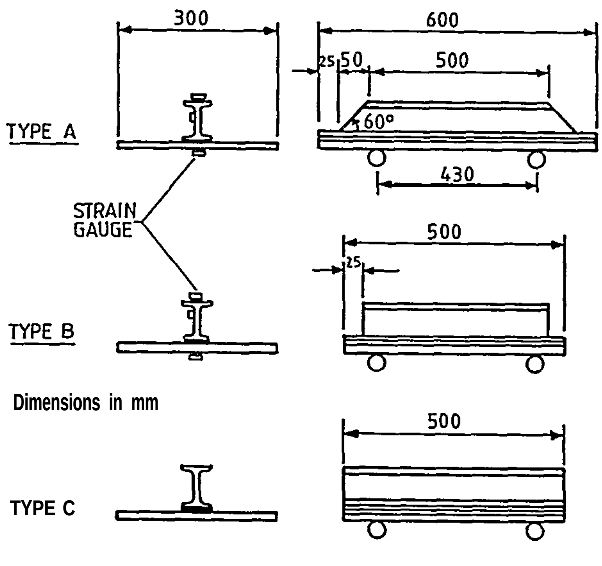


Figure 11 Impact test specimens

Table II - Summary of Impact Test Results

Adhesives: A - Araldite 2007 Elastic Modulus 5 kN/mm2
B - ESP 110 Elastic Modulus 10 kN/mm^2

SPECIMEN	TOTAL ENERGY ABSORBED Joules	DEFORMATION DEPTH mm	DEBOND %
Impacts from stiffener side			
Type A / Adhesive A	565 x 3	7.0	60
Type A / Adhesive B	565 x 2	5.0	100
Type B / Adhesive A	565 x 3	7.0	0
Type C / Adhesive A	195 x 1	2.0	100
Type C / Adhesive A	195 x 3	4.0	100
Impacts from **plate** side - 0.5 mm nominal thickness			
Type A / Adhesive A	420 + 565	1.5	60
Type A / Adhesive B	420 x 1	1.0	5
Type B / Adhesive A	400x2	0.5	100
Impacts from **plate** side - 1.5 to 2.0mm nominal thickness			
Type A / Adhesive A	420 x 1	1.0	100
Type A / Adhesive A	420 x 1	1.0	100

12.5 m was determined. Most impacts were to the stiffener side, but impacts to the plate surface were included for comparison The experiments were repeated on each specimen until a failure occurred

The results of these tests are summarised in Table II in terms of specimen type, the total absorbed energy after repeat impacts (if applicable), depth of any local deformation in the impact zone and the extent of the debond at failure.

In the first three tests it was possible to deduce that the average impact load was about 250 kN and that this induced an adhesive shear stress under the point of impact of about 26N/mm^2. From these results it is possible to conclude that:

- the impact resistance is greatly improved by tapering the stiffener ends thereby reducing end cleavage (types A and B)
- the lower modulus adhesive appears to give better results although no significant difference is evident in small scale shear impact results (see Section 2.1)
- resistance to impact loading is better from the stiffener than the plate side, probably due the greater flexibility and energy absorption in local collapse of the stiffener
- the thinner the bond line the better the impact resistance.

To confirm the implications of these observations, a further series of small scale shear impact specimens were tested to BS 5350 part C4 as shown in Figure 5. In this case the adhesive thickness (Araldite 2007) was carefully controlled to vary from 0.05 to 1.5 mm. The results of these tests are shown in Figure 12. In these tests, the effect of thickness is clearly visible as a progressive decline in impact strength with increasing thickness, the impact strength reducing about 25% across the thickness range.

In itself, this finding does not appear to be all that significant, but the implications of the larger

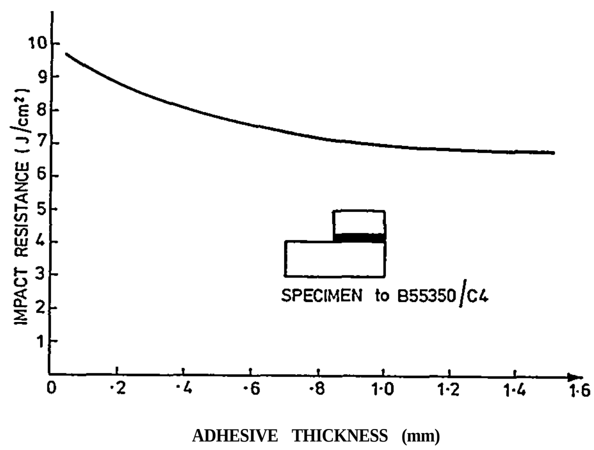


Figure 12 Effect of adhesive thickness on impact resistance (Araldite 2007)

scale impact tests would suggest that the effect of thickness is far more significant in impacts which generate cleavage. In terms of long term structural integrity it therefore seems prudent to take all possible steps to minimise adhesive thickness during bonding processes within large structures, by careful attention to material preparation and clamping (without inducing large residual stresses).

3. SUBSEQUENT DEVELOPMENTS

Since the earlier programme of research outlined in Section 2 there have been a number of short and longer term projects which have enabled other factors to be tackled systematically. In particular, the behaviour of adhesives at elevated temperature, their fatigue strength and long term durability were all important areas of uncertainty which required systematic research. Attention has since been focused on research into steel sandwich structures which appear to offer possible cost effective alternatives to single plate, grillage structures and which would otherwise be difficult to manufacture by welding [29, 30]. In addition, since all the earlier work concentrated only on steel/steel bonding using hot cured epoxy adhesives, attention is now turning to the bonding of dissimilar

materials for marine applications. In conjunction with a number of other UK universities, the Marine Technology Centre at Glasgow has therefore become involved in a collaborative research programme into the practical use of lightweight, fire resistant GRP structures for offshore applications. The bulk of this research at Glasgow is centred on the behaviour of GRP/steel and GRP/GRP joints bonded with two part, cold curing epoxy adhesives [31, 32] which directly complements the earlier studies. This work has been further complemented by a recent student study into the feasibility of bonding steel/timber/steel sandwich panels [33]. An overview of some of the more important findings from these studies is presented in this the rest of this section of the paper.

3.1 Temperature and **Creep** Effects

In order to verify the reduction of shear strength with temperature for the hot cured epoxies used in the previous studies, a number of tensile lap shear specimens to ASTM 3165-73 (see Figure 5) were tested at a loading rate of 0.5 mm/min while contained within an oven at constant preset temperature. The results of these tests are shown in Figure 13 for Araldite 2007. These results indicate the dramatic overall reduction in strength that occurs as temperature increases towards the cure temperature. This reduction is particularly accentuated on either side of the Glass Transition Temperature (T_g) - about 120°C for these adhesives. In general. about 25% of the room temperature strength is lost by 80°C and 70% by the T_g. Beyond 160°C only marginal strength remains until the char temperature of about 25O°C is reached - at which point the adhesive starts to carbonise.

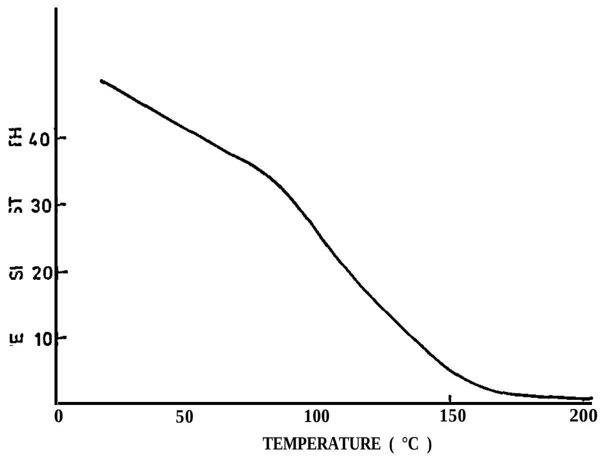


Figure 13 Strength-temperature profile of epoxy adhesive (Araldite 2007)

Not only does temperature affect the ultimate strength directly, but, in common with most plastic materials, it has a dramatic effect on the creep behaviour of the adhesive under sustained load. A continuing series of tests have been undertaken to try to evaluate this effect under a variety of load conditions, Figure 14 illustrates the creep deflection results for two different lap shear specimens maintained at constant temperatures and axial load. In each case the load was set as a percentage of the maximum failure load at room temperature. In the case of the specimen maintained at 130°C it is clear that even at very low stress levels failure will occur in a matter of hours. However, the 80°C specimen

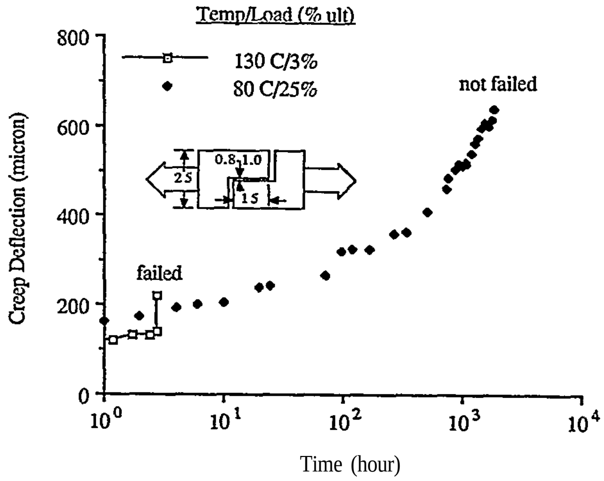


Figure 14 Thermal creep profile of epoxy adhesive (Araldite 2007)

continues to creep at a slow, but predictable, rate without failure for many months. At any given temperature there is a small change in the stress regime which will cause the material to pass into a state of rapid tertiary creep resulting in failure.

The choice of factors of safety for steady or deadloads is therefore critically dependent on the operational temperature regime. Up to 80°C it seems that continuous stress levels of 15 to 20% of the ultimate can be tolerated, although some creep deflection may result. Above this temperature. creep effects become perhaps the major constraint on the use of this class of materials as only limited deadloads can be sustained for any length of time. These results have obvious implications for the behaviour of bonded steel structures in accidental fires and this particular adhesive property is likely to limit application in the first instance to areas where fire performance is unlikely to be critical unless protective insulation is applied. It is worth noting however that this aspect of adhesive performance has never adversely affected their take-up in the aerospace industries.

3.2 Fatigue Strength

There is already a wealth of standard fatigue data available relating to the performance of welded joints. The objective of a range of fatigue studies has been to compare the performance of adhesively bonded joints to this data. In line with the research programme outlined in Section 2.1, interest focussed initially on comparisons with Class F, non-penetrating. fillet welded connections. Test specimens were bonded as shown in Figure 15 to

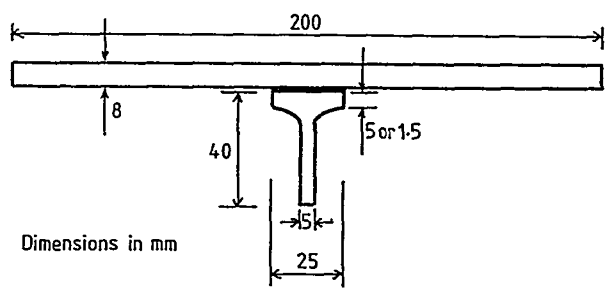


Figure 15 Fatigue endurance testpiece

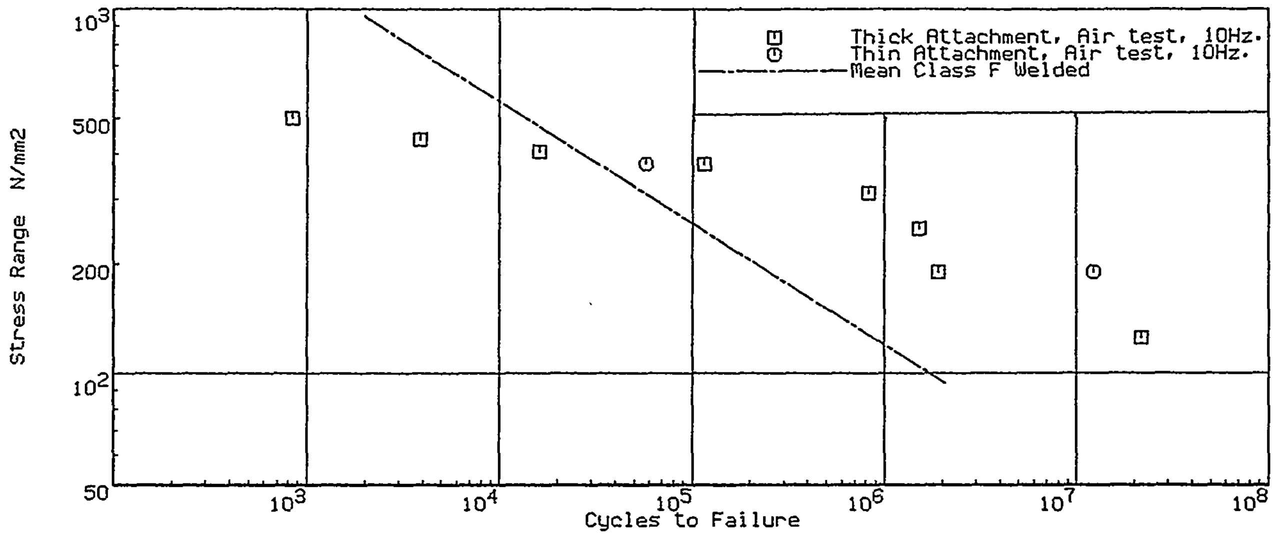


Figure 16 S-N data for adhesive joints compared to mean Class F welded

provide a joint with an unloaded bonded attachment. Constant amplitude fatigue loading with R ratios from 0.17 to 0.5 and a loading frequency of 10 Hz were applied transversely to the line of the stiffener.

The resulting fatigue endurance has been plotted together with the standard mean Class F welded S-N curve to give Figure 16. It can be seen that bonded specimens with both thick and thin attachments perform consistently better than the fillet welded equivalents. This can be explained in terms of the lower stress concentration and lack of residual stress between the low modulus adhesive and the lower stressed skin of the plate. In several examples the plate was observed to suffer fatigue cracking before failure of the joint which suggests that the the adhesive joint fatigue performance is at least as good as the plate material in this class of joint. A complementary series of thick plate (35 mm) bonded fatigue specimens will be tested in the near future.

Other classes of fatigue tests are also under way to compare the performance of bonded sandwich structures (see 3.4 below) with similar structural sections manufactured using through-thickness, laser welding techniques as proposed by the Teesdale et al [34]. Only limited results are currently available from these tests which are somewhat inconclusive. However, a number of small bonded butt joints conforming to the configuration of BS 5447 have indicated a high threshold of fatigue resistance when loaded to about 40% of their static load capacity while carrying an artificial crack-like defect (a sharp saw cut). They have so far sustained more than 5×10^7 cycles without failure or crack growth.

3.3 Durability in the Marine Environment

One of the early objectives of the initial programme of research outlined in Section 2 was to start the process of assessment of durability of steel/steel joints bonded with hot cured epoxy adhesive when exposed to a marine environment. Epoxy materials are naturally inert to hydrocarbon fuels, but can suffer weakening through the effects of plasticisation in contact with water. Furthermore, the possibility of the migration of water molecules to the steel/adhesive interface offers a real threat of degradation through the preferential displacement of the large molecular links formed between the adhesive and steel by those of the smaller, more chemically active. water molecules. Together with the possibilities of corrosion at the interface, there are a number of worries over the durability which are being addressed through two forms of long term experiment.

3.3.1 Unprotected specimens in abiotic sea water

The first study consisted of preparing a large number of standard test specimens of the types illustrated in Figure 5 having their bond surfaces initially primed with a silane. In all cases the spew fillets were left in place. These specimens were then immersed without any further protection in a bath of synthetic sea water to be withdrawn for testing at intervals. After a period of 28 months the first batch of 12 specimens has been tested to destruction in the same manner as the earlier batch of dry specimens discussed in Section 2.1. In this case, however, all specimens were tested in the fully plasticised. wet condition.

The results of each group of three specimens tests are compared in Figure 17 with those of the three original dry specimens for each type of loading. In all cases a small loss of strength can be observed. Losses of 15 to 17% were found for the tensile lap shear and unloaded cleavage specimens, while only 8 to 10% losses were observed in the preloaded cleavage and shear impact specimens. Considering that the latest results were all for fully plasticised specimens these are very encouraging results. Examination of the fractured bond surfaces showed no evidence of any corrosion at the interfaces despite the complete lack of corrosion protection to both the joints and specimens which were otherwise heavily corroded.

The effect of creep in the preloaded cleavage specimens was evident from the reduction in load at the locking screw from 45% of maximum failure load to about 20%.

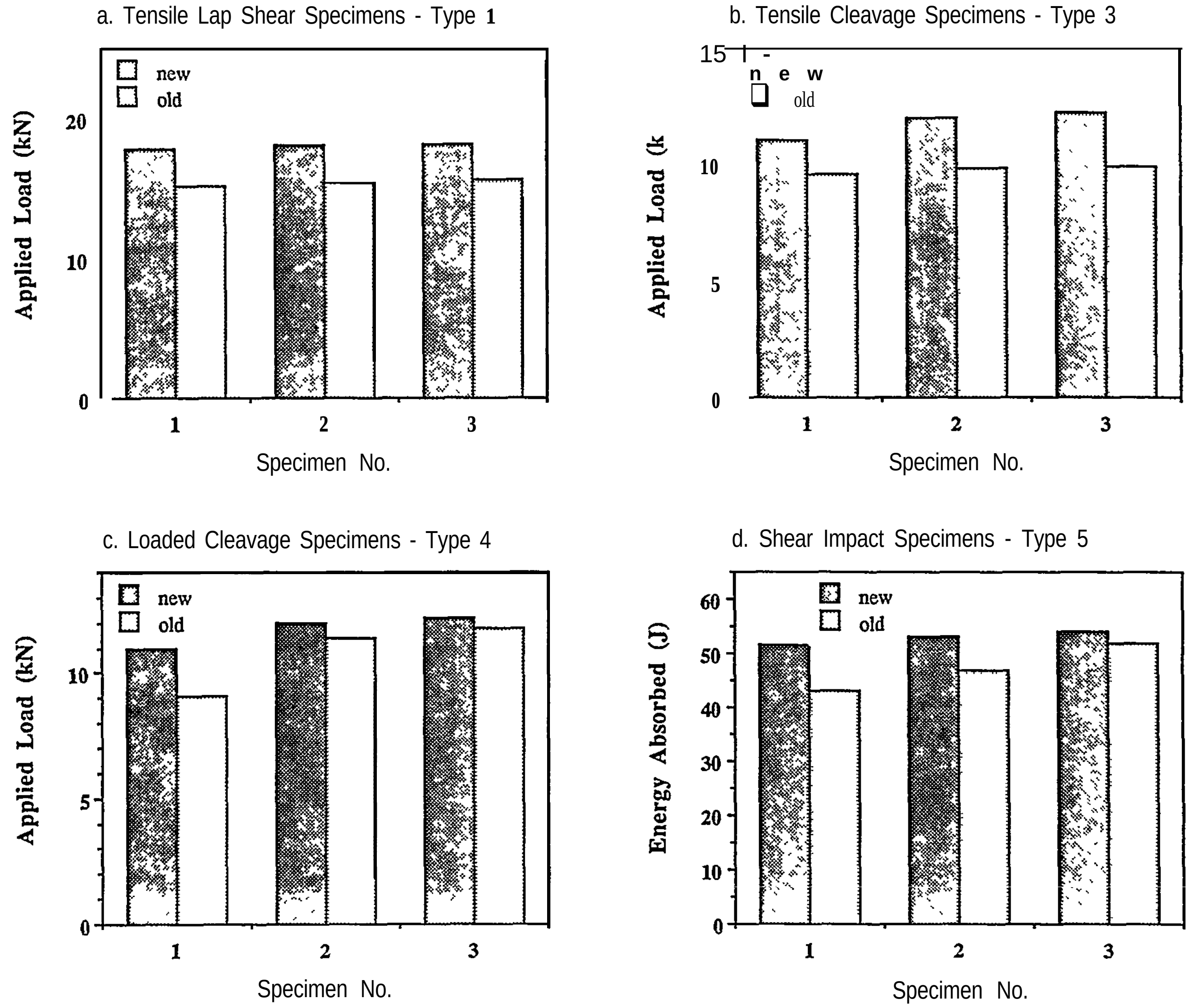


Figure 17 Durability in abiotic sea water after 28 months

3.3.2 Painted **lap shear specimens at sea** under load

In August 1989 a number of tensile lap shear specimens were modified so that they could be strung together with stainless steel shackles to form a chain tensioned by a heavy weight to approximately 10% of failure load - see Figures 18 and 19. This chain is designed so that failure of any one bonded ‘link’ will not influence the remainder. The individual specimens have been bonded either with, or without, silane primers and all were fully coated on top of any spew fillet with an epoxy paint system similar to that used as the primary corrosion barrier in ships. The chain has been suspended from a pier in the intertidal range of the lower Clyde estuary where it is subject to the additional loads of waves and currents. Unless links are observed to fail in situ, it is planned to recover them at intervals in the future for testing to determine the ultimate effects of realistic continuous ‘marine’ exposure.

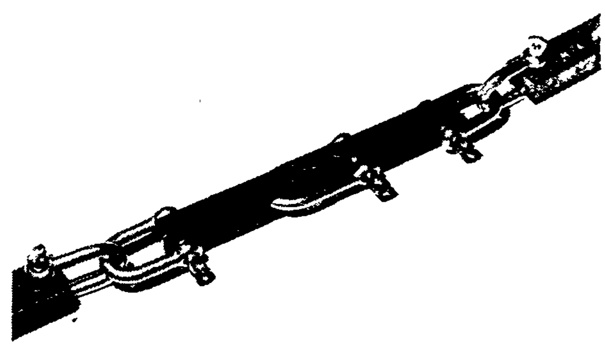


Figure 18 Lap shear joint (modified Figure 5)

3.4 Steel Sandwich Structures

Naval architects have always recognised the theoretical virtue of sandwich structures applied to panels of plating under axial compression or bending. Structural symmetry assures more efficient use of the continuous plate members and allows for the possibility of reduced weight for increased structural stiffness. However, to date such structures are only found in cofferdam bulkhead and side shell structures where the spacing between plates is sufficient to allow for access by welders. In

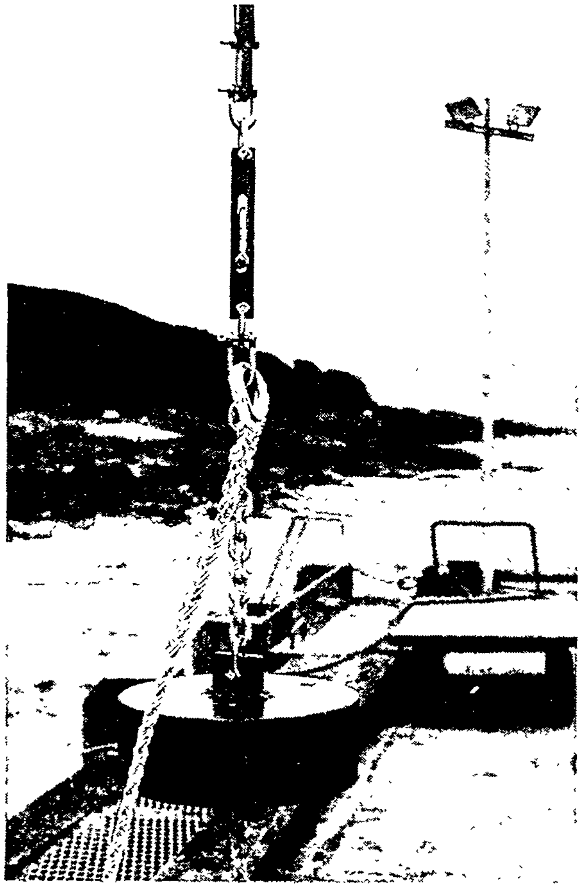


Figure **19** Weighted specimen chain at test site

such situations, the minimum thickness rules adopted for corrosion and abrasion resistance generally cancel out any benefits which might be obtained from increased stiffness and cost and weight increase. It has been recognised [34] that if methods can be found to join the materials reliably, stiff, lightweight, steel sandwich structures could offer advantages in some applications. To date. through-thickness, laser welding has been seriously researched to this end. and although possible, it is rather a long way from being practical. Adhesives, on the other hand, appear to offer a practical alternative if they can be shown to perform well in the stress regimes that are likely to apply.

To shed some light on this problem a short term project [29] compared the performance of fillet welded double skinned, double beam elements (shown in Figure 20) to bonded alternatives. In both cases the specimens were made throughout from 1.5 mm cold rolled steel plate, cut and flanged to form continuous longitudinal channels (75 mm x 15 mm) stabilised by short transverse channels at the loading points. Both ESP 110 and Araldite 2007 adhesives were used in accordance with the techniques indicated in Section 1. All specimens were gradually loaded and unloaded to the point of ultimate structural collapse in three point bending over a span of 600 mm as illustrated in Figure 21. The lack of any distortion due to welding stresses was noticeable in the bonded specimens and may have important implications for the fabrication of very lightweight structures.

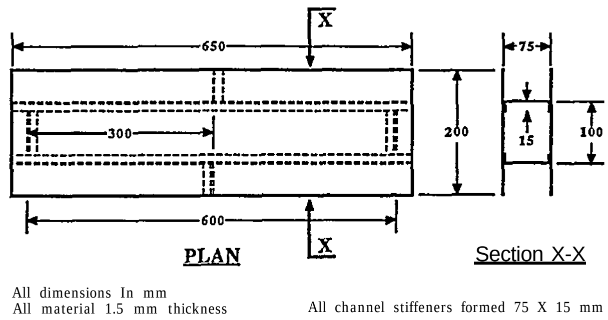


Figure 20 Double skinned. double beam element

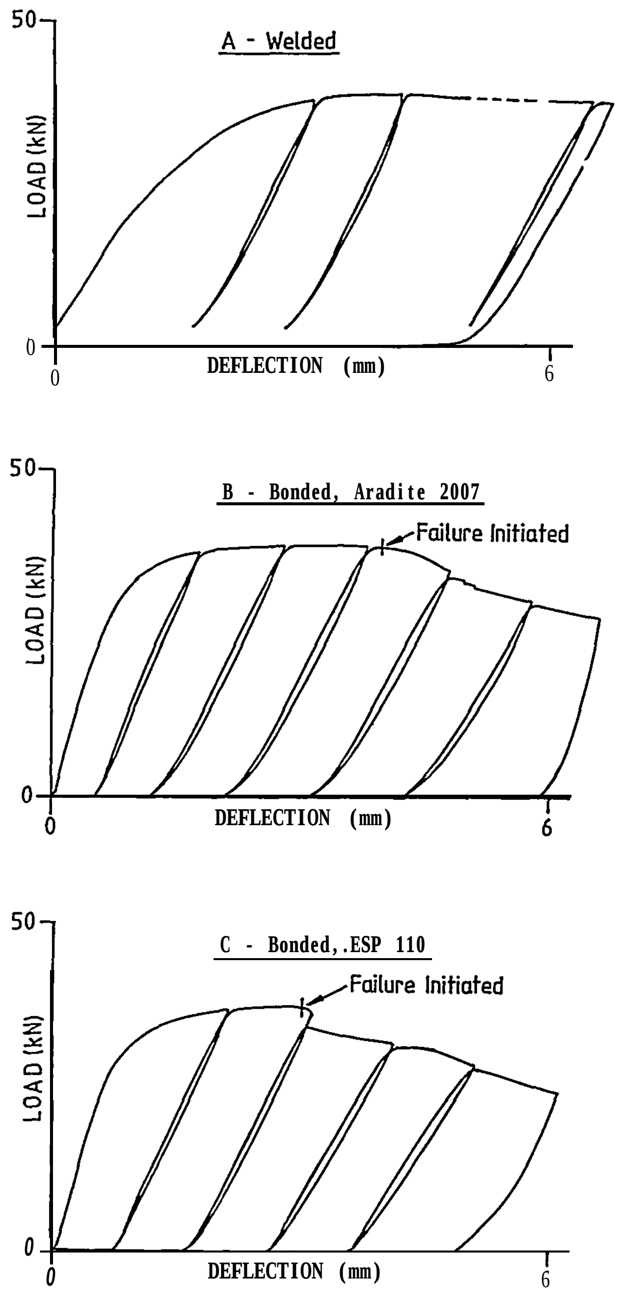


Figure 21 Load-deflection curves for double beam elements in three point bending

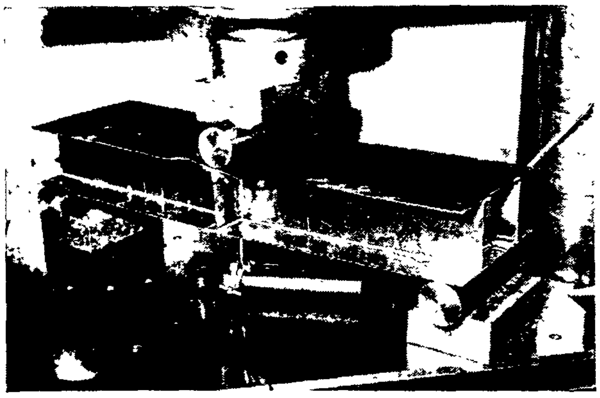


Figure 22 Bonded double beam element at ultimate failure

The load - deflection curves resulting from three of the specimens are shown as Figure 21(a, b and c). All specimens achieved approximately the same ultimate load of 37.5 kN. In doing so. however, the two bonded specimens (Figure 21b and c) displayed much greater stiffness in the elastic region than the welded specimen. This was initially somewhat surprising as the presence of a low modulus material between the flange and web of a composite beam should lead to slightly larger deflections and apparently lower stiffness. On closer examination of the welded specimen it was realised that the fillet weld lines were inducing longitudinal shrinkage of the top of the web which was evident from a rippled surface in the panels of plating between the webs. The bulk of the plating in the flange was therefore relatively ineffective in elastic bending until the specimen had been loaded to its plastic limit. At this point, plastic 'shake-down' results in all the material of the section becoming fully effective again as can be seen in the increased gradient following unloading, which is almost identical to that of the bonded beams. The ultimate failure mechanism of the bonded beams is similar to that of the welded specimen in that the compression flange buckles around the central load point. In the bonded beam elements the upward buckling half wave causes local cleavage/tension failure in the bonded joint - see Figure 22. Continued loading results in a progressive 'unzipping' of this joint, ensuring that considerable plastic load capacity is retained without catastrophic failure.

A more substantial programme of research is now in hand to investigate the structural efficiency, behaviour and feasibility of bonding steel sandwich structures using a variety of internal steel cores, including standard structural sections, and varied forms of corrugations.

3.5 Bonding Steel to Other Materials

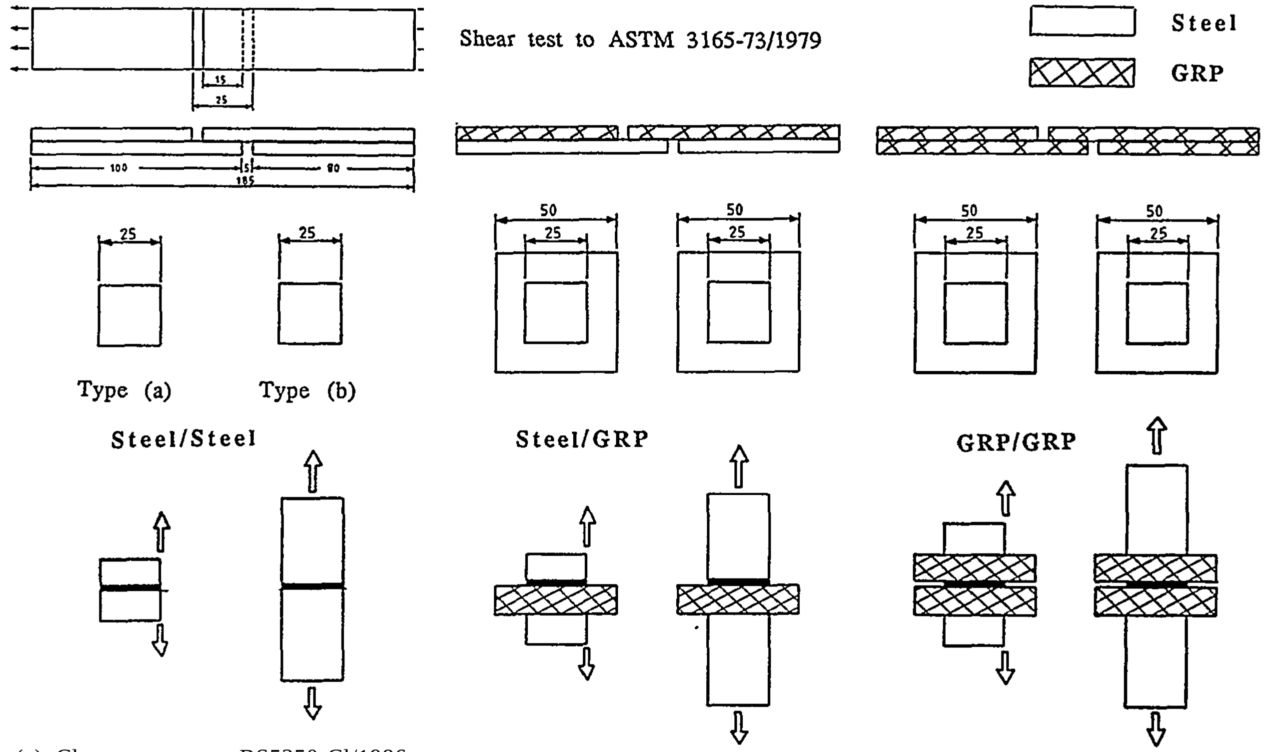
Adhesives have obvious potential for the joining of dissimilar material where the only competitive methods are bolting or rivetting. As both these alternatives cause significant damage through local stress concentration and fretting, the use of adhesives offers a means of spreading loads efficiently without localised damage. However if this is to be done efficiently then the performance of suitable structural adhesives must be assessed in much the same way as has been indicated for steel/steel joints.

Many applications are being proposed for GRP and similar composite materials in the topsides of ships and offshore structures [25, 35, 36]. Apart from minimal maintenance, the benefits are a combination of low modulus (enabling the structural disconnection of superstructures and hull girder) and weight. In addition, such properties as good ballistic resistance and poor thermal conductivity which enable these materials to be considered as major components of fire and blast walls. After the considerable experience gained through the development and production of a long series of GRP mine counter measures vessels (MCMV), it is now possible to manufacture large structural components in such materials with a high degree of confidence in their performance and durability.

Most earlier structures relied on the forming of GRP 'top hat' stiffening members on panel components using the same polyester resins to bond the components as were used in the layup. Modifications of this process now employ flexible acrylic resins at the flange comers to minimise the effect of stress concentrations in this joint [36]. However in topside applications, there are clear advantages in being able to attach such panels to steel stiffening sections which form structural ring frames [25]. In addition. pultruded GRP sections are now available which, together with mass produced flat GRP panels and filament wound tubes, now form the building blocks for a wide range of fabricated GRP structures. Adhesion has a major part to play in all these applications.

As part of a wider collaborative research programme with other UK universities, the properties of a range of two part, cold curing, structural epoxies are being investigated, for application to steel/GRP and GRP/GRP joints. Epoxies are in general quite compatible with, if generally stronger than, the polyester resins used in the relatively low cost polyester, 'E' Glass (woven roving) GRP which has so far been widely used for marine applications. In these studies, it has been particularly important to find adhesives which perform well both in potential fire conditions as well as a marine environment. This has generally been at the sacrifice of other strength properties. In the first instance a comparative study was undertaken into the relative strengths of a range of adhesives using adaptations of the small scale standard tests outlined in Figure 5. In this way the number of candidate adhesives for further testing was reduced to two. To complete the study, a number of steel/steel joints were included to form a reference point for the strength of the other material combinations and to provide a comparison with the hot cured adhesives discussed above.

The results of a range of small scale tests, indicated in Figure 23, are given in Table III, show how the strength of a joint is a function, not so much of the adhesive used, but more of the relative stiffness of the joint and surface energy of the adherends. With metal adherends, joint failure can be adhesive, cohesive or by yield of the adherend itself. With GRP adherends. the failure is generally tensile interlaminar or transverse, either within the resin or at the fibre/resin interface. Surface preparation is a particularly important feature in assuring joint strength. With GRP, some of the best results have been obtained through the use of an



(a) Cleavage test to BS5350-Cl/1986

(b) Tensile test to BS5350-C3/1978

Figure 23 Small test specimens varied adherend combinations

outer peel ply layer, which after removal and degreasing leaves a thin roughened resin layer which requires no further preparation for a reliable bond. The use of peel plies seems to be the most practical way of assuring good preparation in a large fabrication environment through the added protection offered to joint surfaces prior to bonding. The best alternative to the use of peel plies has been found to be shot blasting which provides a good key for the adhesive, but tends to damage the outer fibre layers and leave embedded dust particles.

A small project has recently been completed [33] which considered the viability of combining structural components of timber (birch plywood) with steel. In this case a series of sandwich beams were constructed, similar to those discussed in Section 3.4, in which timber was used as the core material. After some difficulty it was realised that hot cured adhesives were unusable in this configuration because, when hot, the adhesive is drawn off the surface of the joint into the fibres of the timber. Two cold cured adhesives were therefore used - E32A (Permabond) and SP120 (SP Systems). Small scale tests indicated good bending shear stresses performance for cold rolled steel plate bonded to a machine cut cross-section of plywood with outer grain parallel to the joint. In the case of E32A the failure was invariably initiated in the fibres of the parallel grain timber. Replacing the cold formed channel sections shown in Figure 20 with 75 x 24 mm birch ply sections and increasing the plating thickness of the flanges to 2.0 mm, it was possible to obtain ultimate loads of about 48 kN at the mid point of a 550 mm span in three point bending. In all cases failure occurred

Table III - Bond Properties of Araldite 2004 Epoxy Adhesive

(τ and σ = F/Bond Area)

Combination	Specimen No.	Shear Strength		Tensile Strength		Cleavage Strength	
		F (kN)	τ (N/mm^2)	F (kN)	σ (N/mm^2)	F (kN)	σ (N/mm^2)
Steel/Steel	1	13.0	35.0	21.3	34.0	5.2	8.3
	2	12.5	33.0	20.0	32.0	5.1	8.2
	3	12.6	34.0	20.0	32.0	5.2	8.3
Steel/GRP	1	4.9	13.0	9.6	15.4	2.9	4.7
	2	4.8	12.8	10.0	16.0	2.5	4.0
	3	5.0	13.3	8.9	14.3	2.4	3.9
GRP/GRP	1	3.5	9.3	4.9	7.8	2.0	3.4
	2	3.6	9.6	5.0	8.0	2.3	3.7
	3	3.5	9.6	5.2	8.3	2.1	3.4

close to the plastic limit load in the upper (compressive) joint, propagating fairly rapidly to the free edge through failure of the timber as in the small scale tests. In the case of E32A there appeared to be more arrest stages during final failure than with SP120, probably due to the toughened nature of the former adhesive. Throughout the elastic region the stiffness of these composite beams was very close to that predicted by composite beam theory. The joints appeared to be unaffected by the tendency of the timber to creep (most of which is recoverable) under high load.

Although limited, the results of the steel/timber beam study support the more general composites research in suggesting that adhesives offer the possibility of employing a wide range of material combinations in heavily loaded composite structures. A lot remains to be done, however, in establishing the practical limits for such applications.

4. DISCUSSION

Despite the low strength, low modulus and generally brittle nature of most adhesives in their bulk state, it is possible to design joints of high load bearing capacity in a range of adherends that can be applied a wide variety of marine structures. Furthermore, such joints appear able to resist substantial impact and survive plastic deformation of their adherends without catastrophic failure. In particular, the lack of stress concentrations resulting from bonding offer real advantages through the limitation of structural distortion and/or improved fatigue performance. In general it appears that in many configurations the fatigue performance is limited only by that of the adherends themselves.

Durability in the marine environment is still uncertain, as experience can only be gained slowly. The degree of care with which joints are prepared is an important factor in this respect, but given certain minimum standards of preparation and protection. there is little to suggest any long term problem in this respect. Already there is eight years of experience [12] to suggest that the general class of epoxy adhesives appears to suffer little long term degradation in sea water, while experience in the aerospace environment suggests that so far as the durability of this class of adhesive is concerned there are no significant long term problems over periods of 20 years or so.

There are some concerns over the limiting performance of most adhesives with temperature, but this is not a problem so far as day to day operation is concerned for many marine applications. Since most fixed and floating structures must be insulated against the risk of serious fire there are ways in which this weakness, once recognised, can be minimised or eliminated.

The strength of bonded joints depends to a large extent on the stiffness of the adherends and a joint design which avoids the possibilities of significant cleavage stress. Since cleavage is often the by-product of tensile and/or bending stress. this implies the avoidance of such environments and the placing of joints in compression and shear if high loads are to be carried. The designer should therefore refrain from duplicating welded design in detailed design and location of joints and try instead to optimise the advantages of adhesives.

The limiting strength of a bonded joint is largely a function of the stress concentrations at the edges of the joint. Average stress values are useful for comparative assessment, but may be misleading when applied to a design. Great care must therefore be taken in attempting to extrapolate large scale performance from small scale tests. Modification of the spew fillet and local stiffness of the adherends can also have a marked effect on the local stress concentrations and therefore on the performance of the joint itself. The nature of these stress concentrations is generally predicted by detailed Finite Element (FE) analysis, but the fracture/failure process is still poorly understood.

FE analysis can be useful in correlating failure stresses within large joints with those predicted from small scale tests. Figure 24 illustrates the non linear stress distribution predicted from elastic FE stress analysis at the failure load of 20 kN in a tensile lap shear specimen. Although such analysis probably overpredicts the maximum stresses (which are beyond the elastic range of the bulk adhesive). such results are very useful in attempting to quantify stress levels when assessing the failure mechanisms of larger joints Accuracy and reliability are dependent however on careful modelling of the boundary conditions and the various material properties. Accurate modelling of the failure mechanism in particular, and FE analysis in general, is made more difficult by the difficulty of assessing the bulk properties of the adhesive materials themselves and by the many proposed, but still rather uncertain, failure criteria.

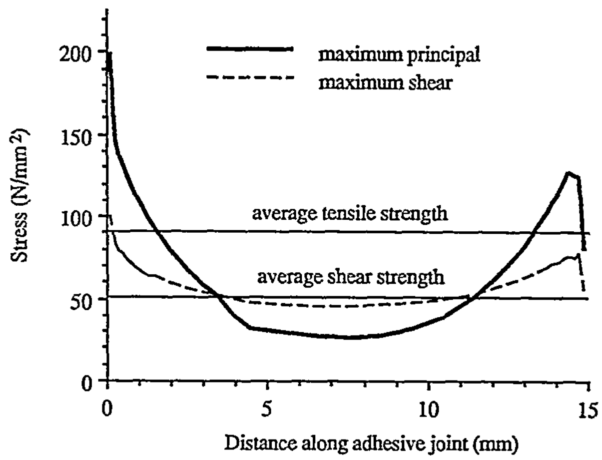


Figure 24 Stress distribution of a lap shear joint at failure

At present it has to be acknowledged that quality assurance is a practical problem associated with assembly of most adherends as the joint, once made, is generally difficult to inspect. Continuity of exposed bond line surface is often a good guide to the continuity of the joint as a whole. but there is no straightforward way of inspecting the degree of bonding once the assembly process is completed. However, under most forms of loading, the edge of the joint is the most highly stressed, and hence the most critical region. Large voids and other defects may be detectable by tap tests [37], but the detection and significance of small voids is not yet well understood [38]. It should always be remembered

that similar quality assurance problems exists with the fleets of composite MCMV's and yet they have not hindered their deployment.

5. CONCLUSIONS

Adhesives are part of a technology slowly coming of age. Welding took more than 20 years to be generally accepted in shipbuilding, but is now dominant. A similar time scale is needed for adhesives to gain general acceptance and for their complementary nature to welding to become fully appreciated. In that time a great deal of research and development is required - but why bother?

- There are new designs that can perhaps only be successfully accomplished with their use.
- Their use in conjunction with welding may result in more cost effective structures.
- Engineers would like to exploit the potential of new materials or combinations of materials to the full in cost effective designs.

As mankind moves inexorably from the surface into subsea environments in the next century innumerable applications for lightweight, reliable structures will emerge, many of which will require the use of sophisticated adhesives. As the applications develop, the adhesives themselves will improve so that many of the problems identified at present will be overcome. Adhesives, and the possibilities they offer for new material combinations, are being launched on a new user community - it is up to that community to determine whether they will float!

6. ACKNOWLEDGEMENTS

Financial and in-kind support for these research programmes is gratefully acknowledged from the following organisations and companies: SERC through the Marine Technology Directorate Ltd., Bostick. Ciba Geigy, Evode, James Howden Loctite, 3M. MOD(N). Permabond, Yarrow Shipbuilders.

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Metric Conversion Table

1 m = 3.28 ft
1 cm = 0.394 in
1 mm = 0.039 in
1 N = 0.225 Ibf
1 kN = 224.8 Ibf
1 J = 0.7376 ft-lbf
1 N/mm2 = 145 Ibf/in^2
$^\circ C = (^\circ F - 32) \times {}^5/_9$

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin, August 21-24.1990

Large Scale Processing Machinery for Fabrication of Composite Hulls and Superstructure

6A-2

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ABSTRACT

Large scale mechanical systems for impregnating and positioning composite materials are now permitting efficient manufacturing of composite hulls to 60 meters (200 ft) and greater. Recreational, commercial, and military vessels fabricated from composite materials are gaining acceptance around the world; however, processing of thermosetting resins and fiber reinforcements in quantities exceeding 90,000 kg (200,000 Ibs) per unit presents a new set of challenges to production engineers responsible for maintaining quality control. Impregnation systems are currently being used at several mine-hunter production shipyards world-wide. Large-to-medium sized recreational yachts are also in production with impregnation systems. This paper will review some past and current impregnator installations, the selection process used for choosing the systems, and production engineering factors.

INTRODUCTION

In recent years, the use of composite materials for fabrication of hulls and superstructures for mine counter-measure vessels MKM), mine-hunter counter-measures (MHC), and minesweeper hunters (MSH) has been fully accepted by naval designers. Advantages of composites over steel have been well documented in numerous tests and include the abilities of surviving multiple explosion shocks while maintaining a low magnetic signature. Peripheral advantages of composite materials include superior resistance to corrosion, very low maintenance, ease of repair, rapid production schedules, and an excellent strength-to-weight ratio, which allows novel hull designs to be utilized

REVIEW OF THE TECHNOLOGY

While fabrication of hulls and superstructures with steel is documented by an extensive body of knowledge gathered through years of experience, composite structures engineers do not have this body of knowledge available for reference. As the plastics industry as a whole evolves at a pace much faster than the metals industry, composite hull technology is also evolving at a rapid pace. While standards for composite or steel military vessels are often set through the same bureaucratic procedures, a problem sometimes exists when military specifications do not reflect the current state of technology. Even with this technology lag, composite-built MCM vessels are out-performing their wood or steel counterparts in every way.

Early Technology

Some of the early production experiments in composite MCM vessels were conducted in the United Kingdom during the construction of the ***HMS Wilton in the*** 1960's. In these early phases, conventional boatbuilding technology typically included hand-mixing of chemicals and application by paintbrush. Using "hand lay-up" methods to produce vessels of this size and complexity had never been attempted before, and the shortcomings soon became apparent. With the encouragement of the British Navy, a project was launched to develop large-scale mechanized equipment for processing glass fibers and impregnating them with polyester resins. Scheduling did not permit an extensive program, however, and this early equipment was abandoned after some limited success.

During this time frame, testing was being conducted in the United States for the development of mechanized lamination equipment. This technology evolved into a product currently available and in use in the world market. The large glass-fiber reinforced plastic panels (FRP/GRP) industry in North America provided a financial base to justify a long-range research and development project.

Barge Covers

The first large-scale commercial success with mechanized impregnation equipment **took** place along the Mississippi River transport corridor. Commercial opportunities opened for fabrication of fiberglass reinforced barge covers as steel barge covers were rapidly damaged by impact and corrosion. These barge covers offered advantages of increasing cubic yards of grain that could be loaded into a single barge. An additional 100 tons of grain could be loaded in each barge through the use of an arched fiberglass cover configuration, allowing a rapid payback on the purchase.

At the peak of this production cycle, over 75 barge covers were produced in a single day at facilities owned by Xerxes-Proform in St. Paul, Louisville, and Paducah,

Kentucky. The demand for fiberglass barge covers became so great that it is reported that over 10% of all fiberglass rovings consumed in the U.S. were processed through the five impregnators installed in these facilities. In order to meet the demand for product, Proform purchased the Kaiser Glass Facility in Seguin, Texas to begin weaving and knitting operations .

Evolution of the Process

During the 1970's, interest in composite MCM vessels began to expand and several vessels were constructed in Europe. During development of equipment for the barge cover projects in North America, it was found that precise pneumatic control systems were necessary to allow draping woven materials in the tight comers and sharp radii of stair steps and hat sections. This motion-control technology was ideally suited for fabrication of MCM vessels with stringent military standards. The Italian Navy settled on composite vessels as the standard method of construction after a series of rigorous tests. Equipment was exported from the United States to Italy for a series of highly successfully composite MCM programs.

ADVANTAGES OF MECHANIZATION

When fabricating with composites, a major determining factor in the control of product quality is the fact that the material itself is actually blended and compounded on-site by skilled or semi-skilled laborers. This is not the case with steel: steel materials are fabricated in raw material production situations with numerous quality-control systems closely monitoring the process.

During the fabrication of composite hulls, materials must be brought together, metered, thoroughly mixed, and de-aerated by a team of fabricators. This is radically different from construction of hulls and superstructures with steel products.

Early experiences with composite fabrication of military vessels were conducted with hand-mixing methods or machine mixing with small-scale spray-gun equipment. While many successes were reported, many quality control problems began to arise that were not easily solvable.

While there were extensive training programs in place to allow welders to achieve a high-quality welding bead (inspected with x-my technology), them were no such formal programs in place for training of composite laminators. This shortcoming manifested itself as a series of quality control problems in early attempts at fabricating composite MCM vessels.

The successful implementation of large-scale machinery in the Italian programs made apparent the tremendous advantage and versatility of centralizing the compounding, mixing, and metering technologies within a single large machine. Through the use of a single machine, it became possible to assign a small team of skilled technicians to maintain, operate, and monitor the processing of the many tons of polyester used to impregnate the woven fiberglass.

Air-Void Content

The key issue in quality control programs for composite MCM vessels is the air content of the laminate as it affects the wetted surfaces of the glass fibers. Early quality control methods established in the United Kingdom concentrated heavily on air-voids as the primary method of monitoring quality. This philosophy was based upon the obvious loss of physical properties that could occur if glass fibers were allowed to remain dry within a laminate, thereby disconnecting the fibers from the physical structure of the matrix. It was determined at the time that "less air means more strength" to the point of counting microscopic bubbles occurring within a cubic centimeter of laminate.

After this standard was firmly entrenched, further analysis determined that air voids were critical only when they prevented surface wetting of glass fibers. It was later found that small air voids falling within the resin matrix, and not contacting fiber surface areas, were not detrimental to physical properties by any significant factor. Because specifications followed by the industry were predicated upon traditional materials such as steel, the time required to review established standards for composites has been much more lengthy than the rate of the expansion of scientific knowledge within the plastics industry.

Because it is theoretically possible to hand-laminate a laboratory sample having a lower air-void content than is possible by machine, the growth of large-scale mechanized equipment has been limited to markets not directly impacted by the standards established by the British Navy. New technology is rapidly bringing the air-void content of impregnator-produced laminations closer to that achievable in laboratory conditions. However, this gap may never be completely closed due to the difference in scale between laboratory samples and the samples obtained from large-scale machinery operating at over 1000 pounds per hour.

REVIEW OF IMPREGNATOR TECHNOLOGY

Early attempts in the U.K. at large-scale mechanization of the impregnation process involved the use of a controlled flat puddle of material through which the glass was pulled. This early technology has since evolved in the United States to a process involving two nip rollers controlling a pool of catalyzed material on either side of the glass fiber (figure 1). An additional set of rubber rollers is sometimes used to feed glass through the nip rollers (as well as preventing the glass from being pulled through by its own weight as it drops to the mold). This technology has since been utilized by shipyards in Italy, the U.K. and Korea as a standard operating method.

Impregnator technology has improved the quality control possible with composite materials and also has reduced labor requirements to 25% of that required with

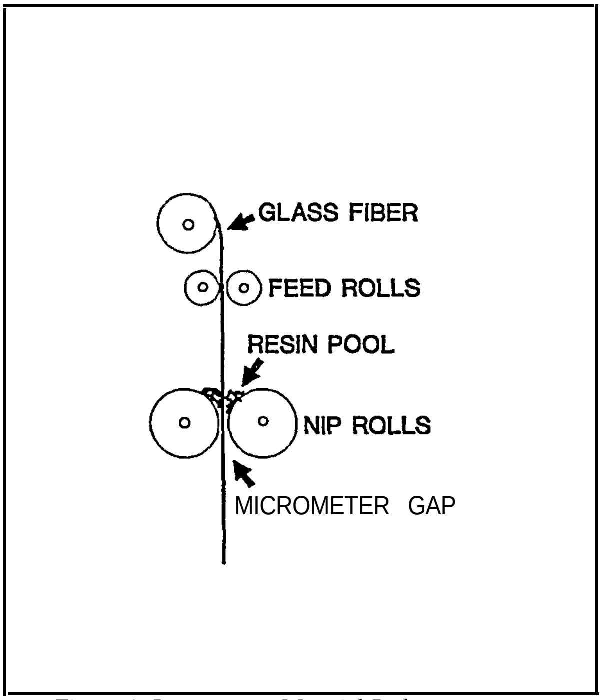

Figure 1. Impregnator Material Path

spray-gun or hand lamination technology. Motion control systems for accurate placement of material have completed the equipment package, to permit fabrication of MCM vessels at a much faster pace than steel fabrication technology has permitted

NEW TECHNOLOGY

World patents have recently been filed describing a radical new approach to Impregnation technology. Previous four-roll Impregnator designs have succeeded in reducing air-void content well below the threshold required to achieve uniform fiber wetting; however, some variation in fiber volume content occurred when the machine was stopped for a significant length of time (allowing resin to further wet the glass fibers and saturate through "wicking"). A machine operated at full linear throughput would usually have a lower fiber volume content than a machine which was intermittently stopped and started Without a skillful crew, this situation could result in some variation of resin content (although quality was still far better than hand-lamination allowed).

Another shortcoming of the four-roll design has been the effect of saturating resin into the glass fibers from both sides of the glass simultaneously, thereby trapping some air within the glass material as the resin meets in the center (figure 2). Even so, the air-void content was still significantly less than that achievable by hand or spray gun when dry glass was laid against a dry mold and a mist of resin was applied over the top of the glass. Achieving high-speed mechanical saturation of the glass without trapping air was the problem to be addressed. Patents have recently been applied for describing a system which moves resin through the glass reinforcement from a single direction, thereby allowing air to move in front of the resin "wave." This new technology allows significant improvement in air-void content to levels approaching those possible in laboratory conditions with hand squeegees.

New Impregnator Technology

By a reconfiguration of the conventional impregnator design (patent applied for), it has become possible to move resin through the glass fiber from one direction only (figure 3). The pool of resin is restricted to one side of the glass fabric as it moves through the sets of Impregnator rollers. A pressure roller is then used to create pressure exerted from the resin-impregnated side of the glass. This tensioning device creates a majority of the impregnation effect in this design.

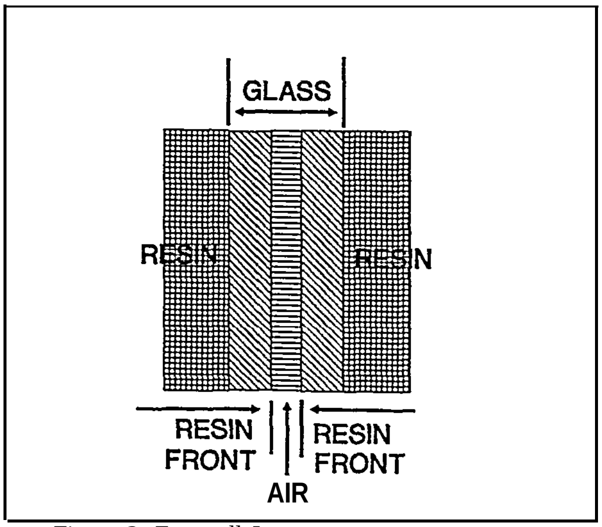

Figure 2. Four-roll Impregnator

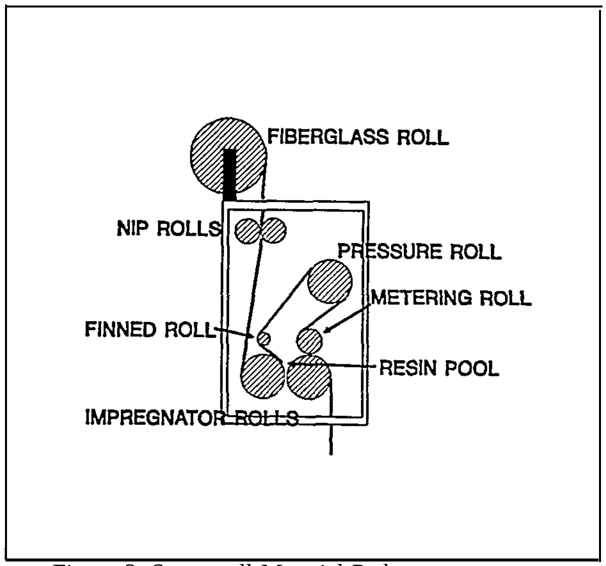

Figure 3. Seven-roll Material Path

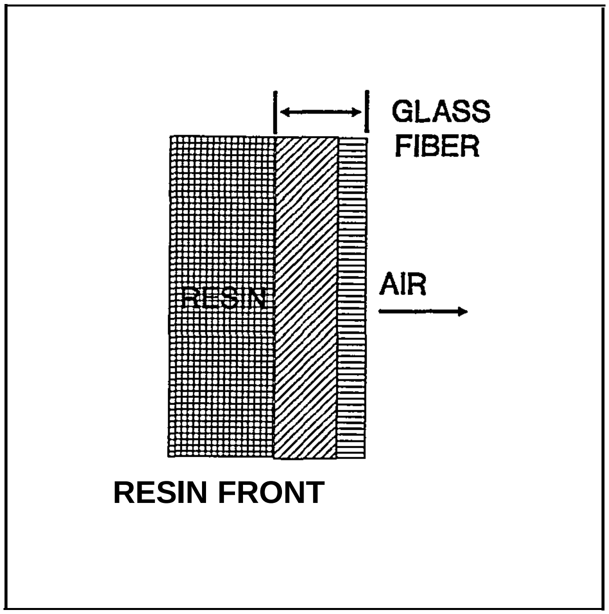

Figure 4. seven-roll Impregnator

By the time the material is returned to the pool for a final wetting, nearly 100% of entrapped air has been expelled through the outside surface of the material (figure 4). An additional saturation by the resin occurs on a cycle of the material through a final micrometer-controlled gap, which determines the final thickness of the wet material (therefore, the fiber-volume-fraction as well). Existing technology is utilized to control the depth of the resin pool automatically with a self-purging liquid level controller.

With air-void content recently being called into question as a major contributor to osmotic blistering, further reductions in air void content can only be beneficial to the ultimate integrity of laminate intended for marine service.

An immediate benefit is also seen during fabrication. A reduction of air voids reduces time requirements for applying multiple layers of laminate and removing air from the material.

OSMOTIC BLISTERING

As more fiberglass vessels are sold throughout the world yearly, the aggregate hours of composite laminate exposure to marine environments increases. The question of osmotic blistering has become a major topic of discussion within the naval architecture community. Osmotic blistering is easily reproduced with hot water testing in laboratory conditions; however, the actual factors contributing to blistering in a marine environment are still subject to discussion. It appears that a number of factors are contributing to osmotic blistering, with poorly mixed catalyst and dry fiberglass being two of the leading culprits.

Laminate samples constructed with either too much or too little catalyst will always result in a decrease of the time required to exhibit blistering. Laboratory experiments also reveal a rapid degeneration of laminates that are constructed with air-voids lying along the surfaces of individual fibers (creating a channel for moisture wicking). Large air-voids also create a site for **moisture to gather** while collecting additional ions to initiate an osmosis process.

Some other factors called into question as contributors to osmotic blisters have been: (1) raw drops of MEKP catalyst overshooting the resin spray fan in external mixing spray equipment; (2) excessively long curing (without abrading) prior to further lamination; (3) insufficient curing before exposure to the marine environment; (4) attempts at production of laminates with extremely high fiber-volume-fractions (resulting in unwetted glass fiber surfaces).

Mechanized production of composite laminates is an obvious means of controlling poor techniques. Impregnation machinery allows the use of centralized metering and mixing pumps, which closely control catalyst-to-resin ratios without intervention by semi-skilled laborers. In the past, contamination of central resin sources has sometimes been a problem in production of MCM vessels. Semi-skilled laborers have even been known to return catalyzed resin to bulk holding tanks to “avoid wasting resin.” Over-catalyzation of the resin to allow “working faster” is also a serious problem where manual labor is relied upon for compounding composite laminates.

MOTION CONTROL SYSTEMS

A primary factor to be addressed by the production engineer is a system for moving the impregnation machine to any point within the mold, at any axis and at any elevation. The primary technology available today for motion control of impregnation systems is described as follows.

Bridge-Crane Impregnator

The overhead bridge-crane has been proven for years as a rapid and efficient means of moving large loads within an industrial area. By adapting this technology to the Bridge-Crane Impregnator (with some improvements), it becomes possible to move the machine on a single horizontal plane to any point within the lamination area. By further mounting the impregnator machine on a rotating turret, it becomes possible to approach the mold surface at any vector required (figure 5). Although variable speed electric motors or hydraulic systems may be used to achieve these movements, pneumatic systems are more commonly used due to their high reliability, ease of maintenance, and acceleration control. Pneumatic motors are typically used to drive the bridge itself north and south with the carriage on the bridge driven east and west (with au additional motor driving the turret in a 360-degree rotation). Another set of controls (possibly operated by another operator) is used to increase and decrease the rate of linear travel of the reinforcement through the machine. Resin flow rate may also be visually monitored within the pool of the nip rollers, or automatic liquid level control devices may be installed (also pneumatically operated).

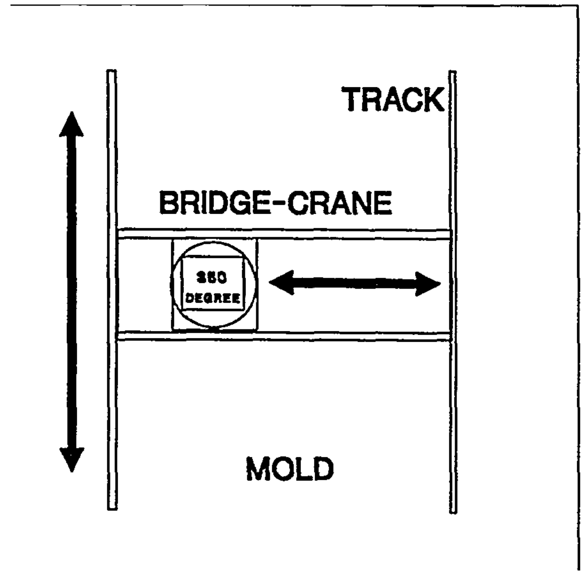

Figure 5. Bridge-Crane Impregnator

Gantry Impregnator

In an extremely large shop or in a shop having an extremely high ceiling clearance, it may become preferable to mount a bridge upon a gantry arrangement (figure 6). Either one or two sets of gantry legs may be used, depending on the availability of a wall for mounting tracks to hold one side of the bridge carriage. A major detriment to gantry arrangements is the necessity of heavy gantry structures to support a free vertical structure, as well as the additional floor space that must be allocated to accommodate the gantry tracks. It is generally preferable to design a building that can support a free bridge span.

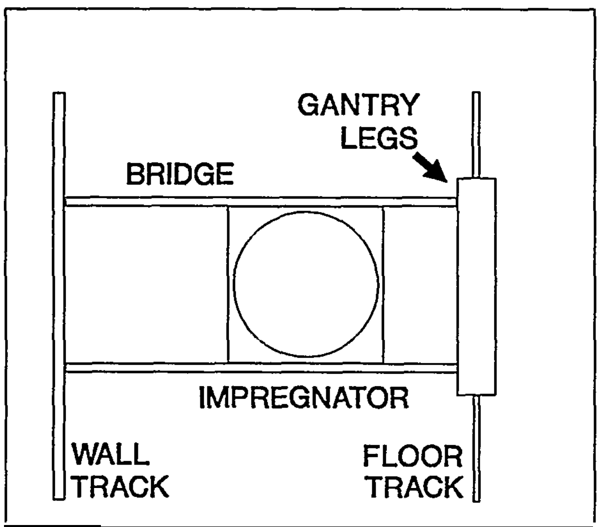

Figure 6. Gantry Impregnator

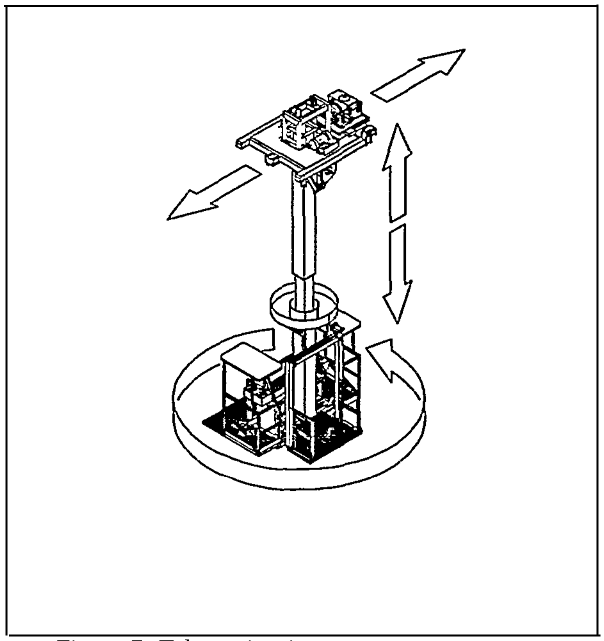

Figure 7. Telescoping impregnator

Telescoping Impregnator

In the lamination of composite MCM vessels, the addition of another axis in the form of a telescoping vertical movement becomes highly desirable due to the increased vertical distance from keel to gunnel. The limitation of most impregnator systems is the amount of vertical material drop that can be tolerated. Excessively heavy lamination suspended from the impregnator will result in slippage through traction rollers and nip rollers, and a loss of laminate and production time. By moving the entire impregnator assembly vertically, through the use of a driven telescope, it becomes possible to position the machine directly next to, or even against, the mold itself for lamination and/or roll-out purposes (see further description of roll-out technology). The Telescoping Impregnator design allows more accurate positioning of material overlaps and also allows working in tight areas such as molded keels and bow contours with tight radii. When laminate must be trimmed during molding of a segment not ending at the gunnel, excessive waste can be avoided by operating the machine in close proximity to the mold .

Mechanized Roll-Out Systems

An additional refinement has recently been made to the telescoping impregnator system allowing mechanical roll-out for air-void removal. Air-void removal has remained a major factor in labor cost, since ultimately, two layers of material must be layered together with subsequent air entrapment between layers. Impregnation equipment (patent applied for) has recently been shipped to the United Kingdom from the United States which permits mechanized roll-out of air in large flat expanses of laminate. As marine structures increase in size and weight, the addition of mechanical roll-out systems become a near necessity.

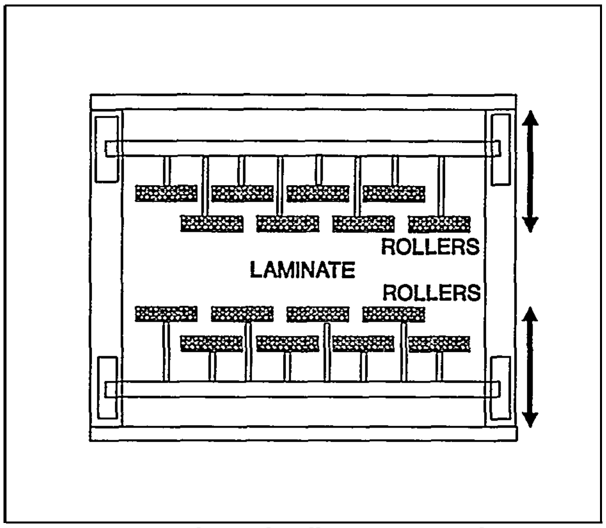

Figure 8. Mechanized Rollout (patent pending)

As seen in figure 8, mechanized roil-out takes place beneath the telescoping impregnator with two sets of reciprocating finned metal rollers similar to those used by hand laminators. The reciprocating movement against the laminate is more rapid and more effective than manual roll-out techniques.

Mechanized roll-out machinery has also been constructed for stand-alone units to be operated independently of impregnator bridge-crane machinery. This allows simultaneous operation of bridge-crane or telescoping impregnators with mechanized roll-out machinery operating in individual work areas.

METER/MIX TECHNOLOGY

Without properly metered and mixed chemistry for the process, composite hull and superstructure production quickly becomes a shaky proposition. An unfortunate characteristic of polyester resin is that poorly mixed and metered polyester materials often appear to the observer to be fully cured. Polyester is extremely forgiving of poor metering and mixing due to the self-propagating cross-linking that quickly penetrates from cured areas to uncured areas. The problem with this characteristic is that slightly undercured areas may not be apparent until years of osmotic blistering have revealed those areas that accept moisture more readily.

Slave Arm Metering

As illustrated in figure 9, the most common method of metering and mixing polyester resin with MEKP (Methyl Ethyl Ketone Peroxide) or BPO (Benzoyl Peroxide) catalyst is the interlocking slave arm pump system. By locking a resin pump with a catalyst pump, it becomes possible to reliably meter polyester and MEKP over extended periods of time. It is generally accepted that a precision-machined catalyst pump constructed of stainless steel materials will out-perform sophisticated electronic digital metering pumps, which are subject to maintenance and training problems. By simply moving the catalyst pump along the length of the slave arm assembly, it is possible to vary the stroke length of the catalyst pump proportionately from 0.5% to 1.5%. Additional catalyst may be metered by the addition of another slave arm pump or by increasing the size of the slave arm pump. A pneumatic powerhead is usually used to power the resin pump as well as the slave arm assembly. Pneumatic drive motors are highly reliable and offer the additional advantage of being non-sparking in a flammable environment. In some instances, it may be desirable to add 2000 watt in-line fluid heaters; contained in appropriate housings, they warm the polyester resin and allow it to be moved more readily through the long hose lengths to the overhead impregnation device. Digital electronics may be utilized to monitor flow rate of resin, catalyst, and fiberglass, thereby monitoring ratios; however, use of computer servo-loops, etc., is usually to be avoided as an unnecessary addition to maintenance problems.

MATERIALS

Polyester Resin

Polyester resin accounts for a vast majority of composite marine structures. Low-cost orthophthalic resin systems are usually selected for recreational vehicles and less critical marine applications. However, as service becomes more severe, many naval architects are specifying isophthalic or vinyl ester systems for composite hulls and superstructures. Analysis of gel coat blistering tendencies has revealed that isophthalic systems and vinyl ester resins offer significant advantages over orthophthalic systems.

Epoxy

When high cruising speed or design tolerances become critical, epoxy laminations are sometimes specified. Epoxy offers greater strength per unit of weight. However, the cost is significantly higher and curing heat is

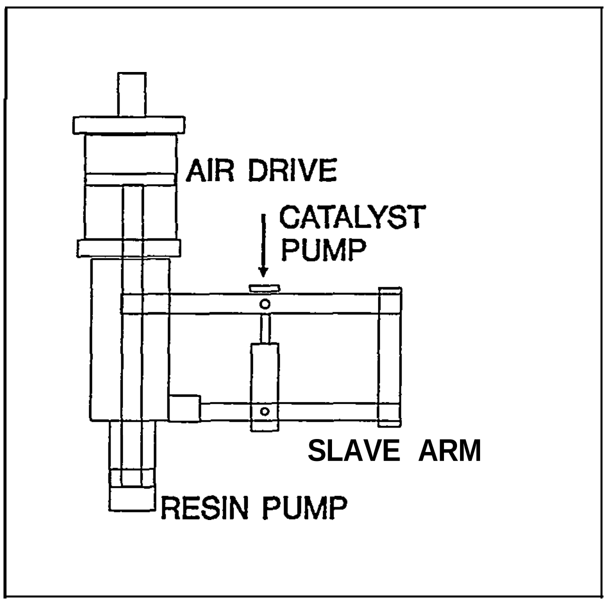

Figure 9. Slave-arm Metering

often required to achieve design specifications. Epoxies are typically higher in viscosity than polyesters and may require vacuum bags or other technology to achieve good wet out during lamination. For these reasons, epoxies are rarely seen in marine vehicles exceeding twenty feet in length.

Phenolic Resins

Recent technology has allowed the U.S. Navy to incorporate phenolic/fiberglass composite armor in deckhouses for the LHD class of multi-purpose amphibious assault ships. Scheduled to be christened in 1991, the USS ***Essex*** will be outfitted with glass fiber/phenolic armor for deckhouse protection. The first marine use of phenolic/fiberglass by the U.S. Navy was for retrofitting the hangar doors of the aircraft carrier USS ***America*** in 1987. Phenolic resins offer advantages of superior fire resistance and low smoke generation when compared to other thermosetting resins. Although phenolics are more brittle than polyester or epoxy, the short-comings in strength may be made up by increased thickness of armor. Phenolic materials have been processed through closed-mold Resin Transfer Molding (RTM) processes and spray-up processes. Some problems exist with the toxicity of phenolics, especially when sprayed in an uncontrolled-fume environment. Phenolics are some of the oldest plastic compounds in existence and are recently showing new promise for fabrication of armor systems for military applications.

REINFORCING FIBERS

Selection of proper reinforcing materials is a huge factor in the success or failure of mechanized production of composite hulls and superstructures. A tremendous variety of woven, knitted, and stitched fiberglass material is available on the market, with other variations of spun and combination materials also being offered as solutions to construction of composite military equipment.

Woven **Roving**

Woven Roving offers a combination of low-cost, easy processability, and ready availability. Woven Roving has a fairly loose weave and easy saturation of resin through the weave structure. Material is easily draped, conforms to complex contours, and readily shifts its configuration to accommodate draping problems. For non-critical applications such as pleasure craft, fishing boats, and other non-combat vessels, simple woven roving structures are economical and offer better-than-adequate strength.

Knitted Reinforcements

When woven roving is subjected to tensile stresses, **the** radii within the woven configuration are pulled straight, thereby allowing additional stress to be transferred to the resin matrix but preventing the fibers from developing their full strength. This situation can be prevented by utilizing fully straightened reinforcements stitched together in layers. This system also allows additional flexibility in designing knitted materials having proportional amounts of reinforcement in the desired direction. Knitted materials or unidirectional materials, unfortunately, offer greater resistance to resin penetration and also naturally develop a higher fiber volume content due to the geometry of the reinforcements. These materials have been commonly processed through impregnators at reduced throughput rates.

Combination Woven/Chop-Strand Mat

Combinations of woven roving and chopped-strand mat have been successfully processed through impregnators for many years. A layer of chopped-strand mat may be stitched or bonded to a layer of woven or knitted roving to achieve a better surface interface through layers of continuous fibers.

Two contacting layers of woven roving may sometimes not achieve a high percentage of contact interfaces where two weaving “peaks” meet between layers. A layer of chopped-strand mat between woven layers greatly improves this interface, but also contributes to thickness and weight of the laminate.

The most successful combinations of materials processed by impregnators to date have been those where the woven material is stitched to the mat with a z-axis fiber. Binders seem to create an additional barrier to resin penetration and allow the chopped-strand mat to fall from the face of the woven roving if suspended from the machine for more than five minutes.

Kevlar and Carbon Fibers

Advanced composite high-modulus reinforcements are not commonly found in the marine industry due to their cost and the minimal impact of weight reduction on a

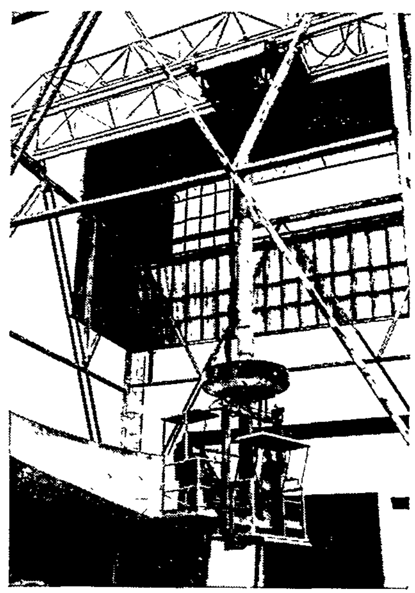

Figure 10. Telescoping Bridge-Crane Impregnator

marine structure design. For high-speed patrol boats and other high-speed vessels, carbon fibers or Kevlar are sometimes used for their high performance characteristics. Carbon fibers and Kevlar® are typically processed as a prepreg to be vacuum bagged and cured by autoclave; however, some success has been achieved with processing through RTM or closed-mold processing methods (where the fibers are closed in a mold prior to injection with meter/mix equipment). Kevlar® has been successfully processed by an impregnator for application in armor plate applications.

CONCLUSION

Large-scale machinery for processing of advanced composites offers an effective means of monitoring and improving quality, and reducing labor. As larger vessels are constructed, especially for military operations, traditional hand-lamination methods no longer offer the precision required to take advantage of the physical properties offered by machine-laid composites. The ordinary quality standards of the recreational boating industry can not and should not be applied to high-displacement vessels or vessels designed for combat applications.

GLOSSARY OF ACRONYMS

BPO Benzoyl peroxide.

FRP Fiber reinforced plastic panels.

MCM Mine hunter counter-measure vessels.

MEKP Methyl ethyl ketone peroxide.

MHX Mine hunter counter measures.

MSH Minesweeper hunters.

RTM Resin transfer molding.

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfisler Hotel, Milwaukee, Wisconsin, August 21-24. 1990

Importance of Considering Life Cycle Maintenance and Modernization Costs in the Design of Navy Ships

6B-1

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ABSTRACT

Experience with maintenance and modernization (M/M) of Navy ships has shown that life cycle maintenance and modernization costs significantly exceed initial acquisition costs, particularly for submarines and complex surface combatants. The purpose of this paper is to draw increased attention to the influence that initial ship design has on the cost of maintenance and modernization of Navy ships, and to emphasize the need for greater consideration of these costs in Navy ship design.

This paper presents several examples of actual design-related maintenance and modernization problems, along with possible design solutions, identified through a survey of U.S. Naval shipyards. The paper also provides recommendations for increasing consideration of maintenance and modernization costs in Navy ship design through education, through the development of specific communication interfaces between design and maintenance and modernization production functions, and through research.

NOMENCLATURE

Maintenance- The term "maintenance" is inclusive of all work performed in a shipyard environment to repair and overhaul ships and their existing infrastructures of components and systems.

Cost- The term "cost" is inclusive of all direct and indirect costs associated with the performance of maintenance and modernization work, including the cost of labor related time.

Shipbuilding/Production- The terms "shipbuilding" and "production" are inclusive of all maintenance and modernization work done in a shipyard environment.

INTRODUCTION

Today's climate of reduced tension between the United States and the Soviet Union is resulting in significant reductions in defense spending. This in turn is resulting in reduced budgets for operation and maintenance of Navy ships. As these budgets decrease, the cost of ship maintenance and modernization is coming under increased scrutiny. Without improvements in the costs of maintenance and modernization, the Navy may be forced to operate with a reduced number of ships, with ships having reduced capability, or with reductions in both numbers and capability.

Most of the attention given to reducing maintenance and modernization costs thus far has been focused on improving productivity of actual work processes within shipyards. Shipyards performing this work have made significant progress in improving the productivity of related work processes. However, focusing attention on shipyard process improvement alone is not enough, as the actual physical execution of the work is only the last step in the whole maintenance and modernization process.

Initial ship design must be recognized as an integral and crucial part of the maintenance and modernization process; the influence that design has on the performance and cost of maintenance and modernization work must be appreciated. The premise of this paper is that the influence of initial Navy ship design on maintenance and modernization costs is not adequately recognized and appreciated, resulting in insufficient attention being given to minimizing these costs during initial design. In these times of ever tightening budgets, increased consideration must be given to maintenance and modernization requirements and costs during initial design of Navy ships in order to assure maximum future Navy capability.

NAVAL SHIPYARD SURVEY

In March 1990 a letter was sent from NAVSEA 072, Naval Shipyard Management Group, to all Naval shipyard Production Officers and Planning Officers requesting examples of design related problems encountered during the course of maintenance and modernization work, along with possible design alternatives that might minimize or eliminate the associated problems. This request was presented solely as a means by which the authors could either support or reject the premise of this paper. In the course of day to day activities at the Naval shipyards, it is not unusual to set aside such requests in way of higher priority production work. Therefore, it was not at all certain what, if any, response would be forthcoming.

During the next six weeks 129 example problems, with suggested design alternatives, were received from six Naval shipyards. Removal of redundant examples, and examples which were not specifically related to design and maintenance and modernization, reduced the data set to 117 usable examples. These remaining examples were then categorized based on commonalities. The percentage of survey responses in each of these categories is shown in Figure 1.

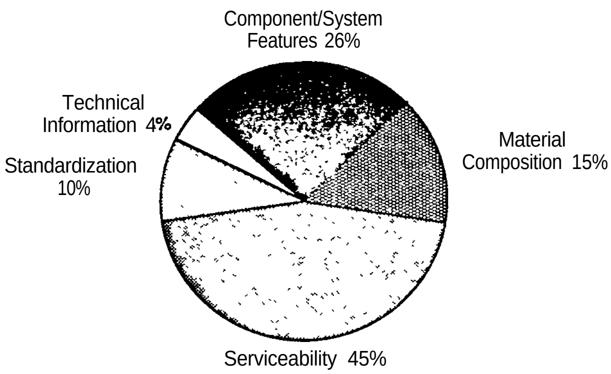

Figure 1. Survey Response By Category

Some examples are very specific while others are quite general. All examples highlighted that to reduce the cost of maintenance and modernization, ship systems should be designed to:

- reduce required maintenance and modernization work through the inclusion of system features which either extend the maintenance cycle or extend the service life of system components, and/or
- simplify required maintenance and modernization work through the inclusion of system features which make this work easier to perform, requiring fewer, manhours and less time.

A short discussion of each problem category, and some of their associated examples follow. Example problem statements and recommendations are reproduced as they were received from the Naval shipyards. There is no intent to suggest that the recommendations received and presented here would be either technically viable, cost effective, or contractually feasible; the intent is to demonstrate that there is a source of information that is not being utilized, and to give examples of the types of things which could be considered in design to reduce life cycle maintenance and modernization costs.

Component/System Features. 30 examples; 26 percent of total. This category includes examples which call for the addition, elimination, or substitution of components and system features.

1) Problem Description: Within the Fleet Modernization Program, the necessity to recable, i.e. rip out entire runs of old cable systems and install new cables for new systems, whenever a new electronics or weapon system is installed during a modernization availability is-the single largest component of electrical cost for this type of modernization work.

   Recommendation: Install signal area networks, similar to computer local area networks, in areas of high congestion in the ship control, communications, and tactical spaces. Redundant capabilities could also be factored into the area networks to enhance survivability. Also, design in ship space for wireways through compartments and passages in areas of continuous modernization (especially electronics/weapons spaces) that accommodate the removal/installation of cable.

2) Problem Description: Bearing temperatures for major submarine rotating machinery units are remotely detected through use of remote temperature detectors (RTDs) imbedded into bearing babbits with epoxy. Bearing oil temperatures are also locally monitored with thermometers at the drain side of the oil from the bearing. Overhaul history has shown that significantly more bearing caps are lifted and bearings removed and worked due to defective RTDs than for actual bearing failures. The relative merit of obtaining actual bearing babbit temperatures is suspect. Loss of oil flow or misalignment, and associated temperature increases would be detected by increases in oil temperature. A casualty of this type would most likely be immediate and would result in bearing damage before any corrective action could be taken.

   Recommendation: Where monitoring of actual temperatures is required, an improved design would be to use tip-sensitive RTDs that make direct contact with the bearing and are inserted through a well in the machinery housing, allowing removal for repair and calibration without having to lift bearing caps or rework bearings. Also, other sensing

devices, such as remote reading thermometers that sense oil temperature as it leaves the bearing, could be used to determine bearing temperature in place of RTDs where practical.

3) Problem Description: Maintenance activities frequently require sound tapes of rotating machinery to make repair determinations. This requires special equipment and frequent trips from the yard to the ship while it is in operation.

   Recommendation: Incorporate sound monitoring equipment into the design of key rotating machinery. This would allow both the ship operation and maintenance activities to have readily accessible information on equipment condition.

4) Problem Description: Ships are not designed to allow adequate access to bilge and tank areas. This makes cleaning of bilge and tank surfaces difficult and leads to inadequate surface preparation and preservation.

   Recommendation: Make bilges and tanks more accessible during initial design. Use corrosion resistant materials in areas that are not readily accessible.

Material Composition. 17 examples; 15 percent of total. This category includes examples which call for material changes to increase the longevity of components. The primary thrust of these examples is to substitute materials which are more resistant to corrosion from sea water and other mediums internal to systems.

1) Problem Description: Extensive weld repair, cleaning, painting, and representation is done to bilge areas during overhaul. Extensive corrosion occurs to the inside of shell plating, stiffeners, foundations and support structure, piping, valve bodies, and machinery.

   Recommendation: Thermal spray a protective layer of aluminum on structure, piping, foundations, etc. during initial building phase to significantly reduce maintenance costs.

2) Problem Description: Corrosion is the Navy's worst maintenance problem. Most sea water components need repair not because of wear, but because of corrosion. The use of ceramic material has greatly reduced corrosion processes in certain applications on surface ships. The use of ceramic materials could greatly increase the life of sea water components and possibly help extend the length of time between overhauls of components and ships, including submarines.

   Recommendation: Allow ceramic material to be used in new and repaired components, such as valve bodies, impellers, and pump casings. A great increase in component life could be realized.

3) Problem Description: Frequent plant shutdowns promote the formation of rust products in the steel shell of main condensers. These rust products are difficult and costly to remove.

   Recommendation: Change the material of main condenser shell and tube supports to a non-ferrous material compatible with the tubes and water treatment being used. The material chosen must be resistant to stress.

4) Problem Description: Deterioration of sea water cooling systems has resulted in routine replacement of 90/10 copper/nickel (CUNI) piping and/or heat exchanger tubes in all classes of surface ships.

   Recommendation: Install 70/30 CUNI piping and heat exchanger tubes exclusively in all sea water systems during initial construction. The thicker cuprous oxide film eliminates or significantly reduces repair costs and more than offsets original acquisition costs.

Serviceability. 53 examples; 45 percent of total. This category includes examples which call for the inclusion of system features which improve the serviceability of the systems.

Several suggestions were received relating to on board shipping routes/accesses for major components. The overhaul and repair process is perturbed by a general inability to rapidly remove major components from the ship. Frequently component removal is delayed until piping and electrical systems are deactivated, secured, and removed. Following is a related example.

1) Problem Description: Standardized plans do not exist for interference removal, internal routing, and specific hull cut locations to support removal of major components. The process of removal/replacement of major components, including making hull access cuts, often require removal of interferences including structure, piping, or other major components, and results in additional work and testing not directly associated with repair/replacement of the primary component. As no standards exist, each activity develops and utilizes its own plans, including location of hull cuts. This results in unnecessary differences between individual ships of a class.

Recommendation: Planned routing for major components (pumps, motors, compressors, etc.) including specific locations and sizes of hull accesses, and associated interference information should be incorporated into original design arrangements and documented on standardized class plans for use by all repair activities. Interference removal should be minimized and, if necessary, provided with mechanical takedown capability to eliminate cutting and rewelding operations. When necessary, hull access cut interferences, particularly piping systems, should be designed with mechanical joints to facilitate ease of removal/reinstallation, maintenance of system cleanliness, and restoration of system operation while the access is open.

Several suggestions were received relating to access for temporary services in support of repair and testing operations. A tour of any ship in the midst of a major overhaul is all that is necessary to explain these concerns. Passageways and accesses are usually congested with temporary services encumbering the free flow of workers and material. Following is a related example.

2) Problem Description: Excessive labor is expended providing temporary service access cuts for temporary power, ventilation, water services, welding cables, etc. These hull cuts must be welded back in later and must be carefully placed to avoid obstruction of. shipping routes and accesses for ship machinery, and to avoid obstruction of ship work.

Recommendation: Provide "Service Access Trunks" to major ship machinery spaces adjacent to emergency personnel access trunks. This is most practical in surface ships and less practical in submarines. This will allow quicker installation of temporary services and avoid obstruction of emergency escape trunks and shipping accesses. Fewer hull cuts will be needed.

Ships' piping and electrical systems generally do not provide connection points for the installation of temporary support systems, for repair process support, and for testing. Several suggestions were received relating to these problems. Two examples follow.

3) Problem Description: During maintenance periods, installation of temporary electrical power is often required (in addition to the ship's normal shore power) while repairs are made to electric plant equipment such as ship service motor generator (SSMG) sets and major electric plant circuit breakers. This type of temporary power is installed directly to the ship's bus and usually requires partial disassembly and reassembly of permanent cabling and/or bus work to facilitate the installation. For example, temporary power is installed to the vital bus while repairs are made to the motor generator-alternating current (MG-AC) breakers, motor generator-turbine generator (MG-TG) breakers, and SSMG set. Also, after major repairs to SSMG sets, ship service turbine generator (SSTG) sets, and diesel generators, the testing mandated by the Deep Diving General Overhaul Specification (DDGOS) predicates the use of load boxes which must be connected directly to the ship's bus. This type of installation requires extensive electrical tagout, is time consuming, and creates additional work within the electric plant.

Recommendation: Design of electric plant switchboards should incorporate permanent connections (cam-lok style) exterior to the switchboards to support installation of temporary power and test equipment. The connectors provided for each vital switchboard should be capable of carrying the rated load of a SSMG set, and the connectors provided for each non-vital switchboard should be capable of carrying the rated load of a SSTG set. These installations could be used for SSMG testing, SSTG testing, diesel generator testing, super shore power, and any other special shore power requirement.

4) Problem Description: Considerable piping system disassembly is often required to support testing and purging.

Recommendation: Provide test/purge connection points/fittings to support all commonly performed evolutions. Standardize connection points/fittings for ease of hookup.

Standardization. 12 examples; 10 percent of total. This category includes examples **which** call for reducing the range of variation in components with similar functions, and reducing the number of applicable specifications.

Problem Description: Electronic systems on board Navy ships use hundreds of different types, styles, and configurations of connectors. Special equipment assemblies, differences in pin sizes, backshells, and adaptors require a wide range of parts support making this method of doing business costly for production, procurement, and engineering (researching substitute components when designed connectors are not available).

Recommendation: Minimize the different types of connectors used (provide incentives if possible) through new system/ship contract specifications. If competition is required, develop the appropriate military standard so that there is a specific connector for each type of Navy cable.

2) Problem Description: Foundations and mounting structure frequently must be rebuilt because replacement mechanical and electrical components do not fit properly.

Recommendation: Use standard design mechanical and electrical components.

3) Problem Description: Present fastener specifications are an accumulation of requirements determined through the years. With the materials available now, there is no apparent need for all the specifications presently in use. Material ordering is extremely complex and cumbersome due to the wide variety of specifications.

Recommendation: Standardize the specifications for fasteners to reduce the quantity of specifications to a more economical number. Many specifications could be combined or eliminated.

Technical Information. 5 examples; 4 percent of total. This category includes examples which call for improving the content and format of technical information (drawings, technical manuals, etc.) provided by design engineering for maintenance and modernization work.

1) Problem Description: Vendor developed detail drawings and assembly drawings are not available for use by maintenance activities. In many cases, NAVSEA (detail dimensional) drawings do not exist, and the vendor considers this information as proprietary and, therefore, does not have a contractual obligation to provide the necessary detailed information. In these instances, and particularly for emergent work, the user activity must utilize a "make as per sample" approach for replacement parts which are not available in the supply system and/or require long lead time for purchase from the vendor.

Recommendation: As part of the initial design process, include all detailed technical information, including vendor detailed drawings, within the ship's drawing index, and make all information available for anticipated and emergent maintenance and replacement work on vendor supplied components.

DESIGN FOR MAINTENANCE AND MODERNIZATION

During initial design of a Navy ship, considerable effort should be given to identifying, reducing, and simplifying ship system and component life cycle maintenance requirements, with special attention being given to maintenance that will be required frequently and/or will be complex and labor intensive. Features should also be provided to simplify anticipated future ship modernization.

However, for maintenance and modernization requirements and costs to be considered in initial Navy ship design:

- minimization of maintenance and modernization costs must be made a design priority, and
- designers, design engineers, and design managers must have experience with maintenance and modernization work and/or have direct and effective communication with production personnel experienced with this type of work.

The results of the Naval shipyard survey show that more could have been done during initial design of existing Navy ships to reduce maintenance and modernization costs. The more recent Trident, DDG-51 and SSN-21 design efforts placed some priority on incorporating design features which will reduce future maintenance and modernization costs; the effectiveness of these design efforts will be seen in the years to come.

In these more recent Navy ship design efforts, priority has been given to "design for production" or "producibility," emphasizing reduction of initial ship construction costs. This emphasis on producibility is primarily a result of U.S. shipyards losing commercial shipbuilding market share because of significantly lower initial construction costs of foreign built commercial ships. Producibility should have priority over maintainability in the design of commercial ships because maintenance and modernization is much less costly for commercial ships than for Navy ships when compared to initial construction costs. However, because of the relatively high costs associated with maintenance and modernization of Navy ships when compared to initial construction costs, maintainability and producibility should have equally high priority in all Navy ship design phases and decisions. Maintainability and producibility can both be incorporated into ship

system design, but only if the importance of maintainability is recognized and accepted by Navy design functions.

> "It is arguable that the conventional design process does not necessarily take into account the operating requirements of maintenance, overhaul, and repair. The design which has been developed to enhance producibility can also enhance operating characteristics." [l]

Also, as noted above, for maintenance and modernization requirements and costs to be considered in initial Navy ship design, designers, design engineers, and design managers must have experience with maintenance and modernization work and/or have direct and effective communication with experienced production personnel.

Research has shown that many engineers and scientists entering ship design and shipbuilding functions today have little or no background in shipbuilding.

> "Of the (shipbuilding and ship design) engineers and scientists surveyed, only 20 percent are naval architects or marine engineers. Those are the only degree programs that have significant content directed specifically towards ship production. This means that the other 80 percent of the entry-level technologists most likely have not been exposed to the shipbuilding industry (and its products, processes, terminology, etc.) prior to graduation." [2]

Shipbuilding research, and the authors' experience suggest that many ship design organizations, particularly in the U.S., have not done an adequate job of training ship designers and design engineers in shipbuilding.

> "In Japan and Scandinavia in particular, shipbuilders have had a clear policy for many years for the training and development of shipbuilding engineers. Elsewhere too many designers are in the position of having to make major decisions having barely seen, let alone worked in a shipyard." [3]

> "The positioning of engineers in the production departments at all levels has been shown by the Japanese to lead to significant benefits, (such as) maintaining a high technology level in production, and promoting superior communication. In U.S. shipyards the duties and responsibilities of such engineers could be equivalent to those in Japanese shipyards, where they are involved in planning, scheduling, material flow, accuracy control, and manning requirements for their areas of responsibility, or ***they*** may be ***restricted to the usual U.S. role of engineering liaison*** (emphasis added)." [4]

There are a relatively small number of engineers in U.S. shipyards who work in ship production areas as trades supervisors, process analysts, production controllers, planners, accuracy control engineers, etc. In Naval shipyards, the majority of these engineers work within the industrial engineering organizations. These engineers have gained valuable shipbuilding experience.

> "There are still many untapped opportunities for our industrial engineering efforts. . ..Our ship designs have rarely given adequate consideration to maintainability - our industrial engineers have the necessary skills to identify changes which can be made in ship design to improve access and repairability, without compromising the system technical requirements." [5]

There are also managers, supervisors, and mechanics on the waterfront without engineering backgrounds who, nevertheless, are extremely knowledgeable in their specific areas of production, and, in the Total Quality Management sense, are probably the most knowledgeable of specific maintenance and modernization problems related to design.

Given the present level of shipbuilding experience in design organizations, another way of identifying maintenance and modernization cost saving ideas for new Navy' ship designs is to have a direct and effective means of communication between design and the experienced production personnel mentioned above.

Following are descriptions of the existing communication interfaces between government design functions and Naval shipyard production related functions.

- In 1984, the Naval Sea Systems Command (NAVSEA) established a working interface between Naval shipyards and design engineering to review proposed <u>design changes</u> for cost and schedule impact.

- In 1986, NAVSEA initiated a study for maintainability that focused on the aircraft carrier hull expansion program.
- In 1987, NAVSEA initiated reviews of specifications. drawings, standards. and handbooks through participation as a member of the NAVSEA Specifications Control Board.
- In 1987, NAVSEA began reviewing Integrated Logistic **Support** Plans.
- In 1987, Navy design engineering began reviewing Uniform Industrial Process Instructions (UIPIs), developed by Industrial Engineering in Naval shipyards, for their ability to produce products that meet technical requirements.
- The recent Hazardous Waste Minimization Program requires production to communicate to design engineering when it is known that a specific job can be done alternatively excluding or minimizing hazardous material. Design engineering is required to respond. [6]

Some of these activities represent after-the-fact reviews by NAVSEA of design generated material for existing ships. The maintainability study of the aircraft carrier hull expansion program was a one-time-only activity. The Navy design engineering reviews of UIPIs only address the technical applicability of production processes. None of these activities provide a means of communicating specific design ideas for reducing maintenance and modernization costs between production and design functions. It has been the authors' experience that little or no communication interface exists today for this specific purpose.

CONCLUSIONS

- The survey response supports the premise of this paper that the influence of initial Navy ship design on maintenance and modernization costs is not adequately recognized and appreciated.

- Changes in Navy ship design can contribute to significant reduction of life cycle maintenance and modernization costs.

- Maintainability must be given the same priority as producibility in initial design of Navy ships.

- Navy ship designers, design engineers, and design managers require additional education, training, and experience in shipbuilding.

- There are many ideas available from shipyard personnel relating to design improvements which could help reduce maintenance and modernization costs.

- There is presently no formal and effective means of communicating ideas related to reducing maintenance and modernization costs between design and experienced shipyard personnel.

- There are presently no recognized and published generic design methods and attributes which are known to contribute to reducing maintenance and modernization costs.

RECOMMENDATIONS

- Provide shipbuilding education and training to undergraduate designers and engineers who will be entering the ship design field. Include programs through which these students can obtain hands-on shipbuilding experience; successful co-op and internship programs already exist through several colleges and shipyards. Most naval architecture programs today have minimum requirements for studies in ship production. These education and training programs should emphasize equally the need for maintainability and producibility in Navy ship design.

- Provide shipbuilding education and training to existing Navy ship designers and design engineers. Include a means for designers and design engineers to obtain hands-on shipbuilding experience, particularly with maintenance and modernization work. These education and training programs should emphasize equally the need for maintainability and producibility in Navy ship design.

- Establish formal and effective communication interfaces between production and the Navy design functions for discussing design ideas related to maintenance and modernization cost saving.

- Establish methods of cost-benefit analysis that would be applicable to judging the economical merit of design related maintenance and modernization cost saving ideas, such as the ones presented in this paper.

Conduct research to identify generic design methods and attributes which would contribute to reduction of maintenance and modernization costs, and to study how these methods and attributes might coincide or conflict with the already established methods and attributes which contribute to producibility.

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Pfister Hotel, Milwaukee, Wisconsin. August 21-24,1990

CAD/CAM in Phased Maintenance

6B-2

Bruce A. Carr, Visitor, **Thomas M. Houlihan,** Visitor, **Michael A. Polini,** Member, Jonathan Corporation, Norfolk VA

ABSTRACT

The Jonathan Corporation is a medium sired engineering company specializing in Naval ship repair. The bulk of corporate work centers on the Phased Maintenance (PM) of three classes of ships. Typically, each PM contract covers three to five different ships per class scheduled for 90 day Availabilities at approximately one year intervals over a period of five years.
The type of work to be performed during each Phased Maintenance Availability (PMA) falls into one of two categories - ship alterations or ship repairs. The first group, ship alterations, are characterized by detailed, long lead engineering and planniig efforts, typically beginning 540 days prior to the vessels's arrival The second group. ship repairs, make up the other end of the spectrum with short lead times and compressed service details. The majority of repair items are identified 60 days prior to an Availability, while some are not determined until after the vessel has arrived in the shipyard.

The Engineering Department that services PMA work is composed of three disciplines - Structural. Mechanical and Electrical. The Mechanical Discipline is further sub-divided into the areas of Machinery and Piping/HVAC. While the nature of PMA work within each discipline is peculiar to the application, the process is similar in each. Reference information is gathered and verified, technical analysis is provided where necessary, and detailed drawings are prepared and submitted for Navy approval prior to shipyard production. All drawings are developed using two-dimensional (2D) drafting techniques at various sites by teams of Computer Aided Design (CAD) input operators utilizing color graphic workstations on a multi-shift basis as required by the workload. Completed drawings are transferred to the engineering site over a network link, where additional workstations are available for engineers to check and correct them as necessary.

PMA OPERATIONS

PMA Operations involve four distinct agencies - Engineering, Purchasing, Production and Management. Each is now considered in detail.

PMA Engineering

PMA Engineering encompasses both engineering design and production planning. As Ship Installation Drawings (SEX) near completion, the PMA planning process begins. For each PMA tasking, engineers experienced in the production trades and familiar with the company's resources prepare a work breakdown structure which features units called work elements. Typically, these elements encompass work that can be done by a single person in 16 hours or less. Detailed information specific to the element. such as primary work operations. secondary work operations, associated trade&ills, material requirements, manhour estimates, specific references and a verbal description of each element tasking, is loaded into a database residing on the central corporate computer system. Once identified, the elements for the various trades are then grouped together into production work packages (Figure 1) Which represent 200 - 400 manhours of work for a crew of 6 - 8 people.

PMA Purchasing

Upon completion of the work breakdown structure, PMA Purchasing commences. The database is searched for elements flagged by the engineers as requiring material. Sources are identified, cost estimates are prepared and tentative delivery schedules are set by seasoned procurement personnel. A material audit list is prepared linking the material purchased to a particular element the governing alteration and the applicable drawing for tracking purposes (Figure 2).

PMA Production

Ninety days prior to ship arrival, PMA production personnel review the work packages prepared for the ship alterations, the list of repairs and associated manpower requirements. Decisions are then reached on the exact scope of work to be performed and the operative production schedule is finalized. The job database is the updated and work is released in the form of work packages. The packages contain all the pertinent information concerning the work to be performed. Upon completion of each task, the expended time is recorded for each associated work element in a work package and the elements are then closed to further hourly charges being entered into the database. Various production efficiencies (Figure 3) are calculated from these expended and completed hour values to determine tasking progress.

PMA Management

While all this activity is taking place, PMA management personnel are working to control the job. Manpower loadings are developed and work schedules are continually adjusted to level out the production peaks and valleys (Figure 4). The process is facilitated by use of the Interactive Project Scheduling System (IPSS) developed to expedite the scheduling of PMAs and the setting of trade skill manloading levels. As work is completed, actual status from closed out work elements is entered into the database, enabling overall job progress to be monitored.

CAD/CAM SYSTEM DESIGN

Several considerations involving the work place, proposed and operative hardware as well as proposed and operative software were involved in the present Computer Aided Design / Computer Aided Manufacturing (CAD/CAM) System Design. Each is now considered in detail.

Working Environment

Before getting down to specifics. it is best to summarize the operating work environment First is the fact that it is diverse. The parts associated with the Structural discipline range from rectangular steel panels measuring 10' x 40' to circular aluminum 3" diameter insert plates. Electrical discipline needs may be for a 1/8" steel plate dotted with 2" x 3" rectangular cutouts for mounting recessed gages.

Mar 7. 1986 Jonathan Carp (Front St.C) time 14, 19

PACKAGE WORK SHEET

Package 113.00 87K MODS 4TH AND 5TH DECK Ships 1315 USS SAGINAW (LST-1188) FY88

programs signature	date	budget	.00
start date 01/15/86	completion date 02/01/88	planner: 9643 Elbert P. Williams	rov e 6
leadcraft shipfitter		primary operation modify	

line	wo #	Item -- paragraph 100	pri	trade	100 operation	subject	bdt	bdt	location
1>	6496	529-90-087 3.3.1	4	110	02 layout/template	LOCATION FOR DPHM 11-E	4	0.00	5-192-0-E
2>	8499	529-90-067 3.3.1	4	110	63 install equip/str	BOLTED PLATE MANHOLES 11-E	12	0.00	5-192-O-E
3>	8600	529-90-067 3.3.1.1	4	605	69 control point	INSPECT FINAL WELDS	4	0.00	5-192-0-E
4>	8501	529-90-067 3.3.1.1	4	130	67 weld/burn	BOLTED PLATE MANHOLE 11-E	16	0.00	5-192-0-E
5>	8602	529-90-067 3.3.1	4	110	63 Install quip/str	KIT 761 DFT 11-C COLLARS	16	0.00	5-192-O-E
6>	8503	529-90-067 3.3.1	4	130	66 cut	ASSIST 110 W/DET 11-C COLLARS	16	0.00	5-192-0-E
7>	8504	529-90-067 3.3.1.1	4	605	69 control point	IHSP FINAL WELDS	4	0.00	5-192-O-E
8>	8603	529-90-067 3.3.1.1	4	130	67 weld/burn	DET 11-C COLLARS STOP	86	0.00	5-192-O-E
9>	8606	529-90-067 3.3.1.1	4	605	69 control point	**INSP** FINAL WELDS	4	0.00	5-192-0-E
10>	8507	529-90-067 3.3.1.1	4	130	67 weld/burn	DET 11-C COLLARS PORT	40	0.00	5-192-0-E
11>	8608	529-90-067 3.3.1	4	110	63 Install equip/str	SECT 14-A BLANKS	24	0.00	5-192-0-E
12>	6509	529-90-067 3.3.1	4	130	66 cut	CUT DRAIN HOLE BLANKS 14-A	4	0.00	5-192-0-E
13>	8510	529-90-067 3.3.1.1	4	805	69 control point	INSPECT FINAL WELDS	4	0.00	5-192-0-6
14>	8511	529-90-067 3.3.1.1	4	130	67 weld/burn	DRAIN HOLE BLANKS 14-A	40	0.00	**5-192-0-E**
15>	9512	529-90-067 3.3.1	4	110	63 Install equip/str	SECT 14-C ACCESS COAMINOS	1	0.00	**5-192-0-E**
16>	6513	529-90-067 3.3.1.1	4	605	69 control point	INSPECT FINAL WELDS	2	0.00	**5-192-0-E**
17>	6514	529-90-067 3.3.1.1	4	130	87 weld/burn	SECT 14-C ACCESS **COAMING**	6	0.00	5-192-0-E
18>	8515	529-90-067 3.3.1	4	110	63 install equip/str	SECT 14-D ACCESS COAMINGS	8	0.00	5-192-O-E
19>	8516	529-90-067 3.3.1.1	4	605	69 control point	INSPECT FINAL WELDS	2	0.00	5-92-O-E
20>	0517	529-90-067 3.3.1.1	4	130	67 Wold/burn	SECT 14-D ACCESS **COAMING**	6	0.00	5-192-0-E
21>	6653	529 9O-067 3.3.2	4	110	55 remove equip/stru	3-TYPE"S" DINS/5 STOR DINS	36	0.00	4-203-2-A

Figure 1 Production Work Package Cover Sheet

dec 14, 1987 Jonathan corp (front St, L)

PACKAGE WORK SHEET

Package: 908.00 D-ALT KITS / PROGRAM / TSC Ship: 1315 USS SAGINAW (LST-1100) fV88

material requirements:

wo#	mic#	qty UM	Description	requisition	Class	promised	received	whse loc
7809	7234	2 SF	PLATE, CRES (304) 1/4 T 10.2 LB/SF 00-S-766	356653-003	CAM-T.STL.	l/05/88		
7871	7243	28 SF	PLATE.STEEL ORD STR 1/2-T 20.4 LB/SF WIL-S-22690 GR A CL U	356217-032	CAM-T.STL.	12/22/87		
7871	7244	27 SF	PLATE.STFEL ORD STA 3/A-T 15.3 LU/51 WIL-S-22698 GR A CL U	366217-033	CAM-T.STI	12/22/07		
7871	7245	2 SF	PLATE.STEEL ORD STR 1/4-T 10.2 LB/SF WIL-5-22608 GR A CL U	356217-034	CAM-T.STL.	12/22/67		
7871	7246	11 FT	FLAT BAR.STELL ORD STA 1/4T X 4W WIL-S-22698 GR A CL U	356217-035	T. STL BUY			
7871	7552	1 EA	COC FOR WIC #7243	356217-036	FILE CLEANUP		12/14/67	173480
8186	7489	3 SF	PLATE.STEEL ORD STR 3/8'T 15.3 LB/SF WIL-S-22696 GR A CL U	356652-003	CAM-T.STL.	12/22/67		
8300	7559	1 SF	PLATE.STEEL ORD STR 1/4'T 10.2 LB/SF WIL-S-22698 GR A CL U CAM MATERIAL	358342-001	CAM-T.STL.	12/22/87		
8300	7560	1 SF	PLATE.STEEL ORD STA 1/2'T 20.4 LB/SF MIIL-S-22698 GR A CL U CAM MATERIAL	358342-002	CAM-T.STL.	12/22/87		
8300	8170	1 EA	COC FOR MIC # 7560	358342-003	FILE CLEANUP		l2/14/87	273480
8310	7563	40 SF	PLATE.STEEL ORD STR 3/4'T 30.6 LB/SF MIL-S-22698 GR A CL U CAM MATERIAL	356342-006	CAM-T.STL.	l2/22/87		
8310	7564	40 SF	PLATE.STEEL ORD STR l/2'T 20.4 LB/SF MIL-S-22698 GR A CL U CAM MATERIAL	358342-007	CAM-T.STL.	l2/22/67		
8310	7565	6 SF	PLATE.STEEL ORD STR 1'T 40.6 LB/SF MIL-S-22698 GR A CL U CAM MATERIAL	356342-008	CAM-T.STL.	12/22/87		
8310	7566	4 SF	PLATE.STEEL ORD STR 3/8'T 15.3 LB/SF MIL-S-22698 GR A CL U CAM MATERIAL	356342-009	CAM-T.STL.	12/22/87		
8310	7567	5 SF	PLATE.STEEL ORD STR 5/6'T 25.5 LB/SF MIL-S-22698 GR A CL U CAM MATERIAL	356342-010	CAM-T.STL.	1/19/87		

Figure 2 **Work Package Material Listing**

OCt 7, 1987 time: 17:09 JONATHAN CORPORATION PAGE 0001

WORK PACKAGE EFFICIENCIES

- (VReport for JONATHAN internal use only) -

Pkg NO	Hours Budget	Hours Exp	Prod Eff	Hours Comp	Hours Budget	Prod Eff
210.00	114.00	104.00	109.615	114.00	114.00	100.000
211.000	106.00	63.00	168.253	106.00	106.00	100.000
212.00	110.00	153.25	71.776	110.00	110.00	100.000
213.00	73.00	18.00	405.555	73.00	73.00	100.000
214.00	376.00	362.50	103.724	376.00	376.00	100.000
215.00	302.00	333.50	90.554	300.00	302.00	99.337
216.00	259.00	154.50	167.637	86.00	259.00	33.204
217.00	468.00	16.00	3050.000	227.00	488.00	46.516
218.00	130.00	110.00	116.161	82.00	130.00	63.076
219.00	125.00	82.00	152.439	117.00	125.00	93.600
220.00	67.00	6.00	837.500	67.00	67.00	100.000
Final Totals	2150.00	1404.75	153.052	1658.00	2150.00	77.116

Figure 3 **Work Package Efficiencies Report**

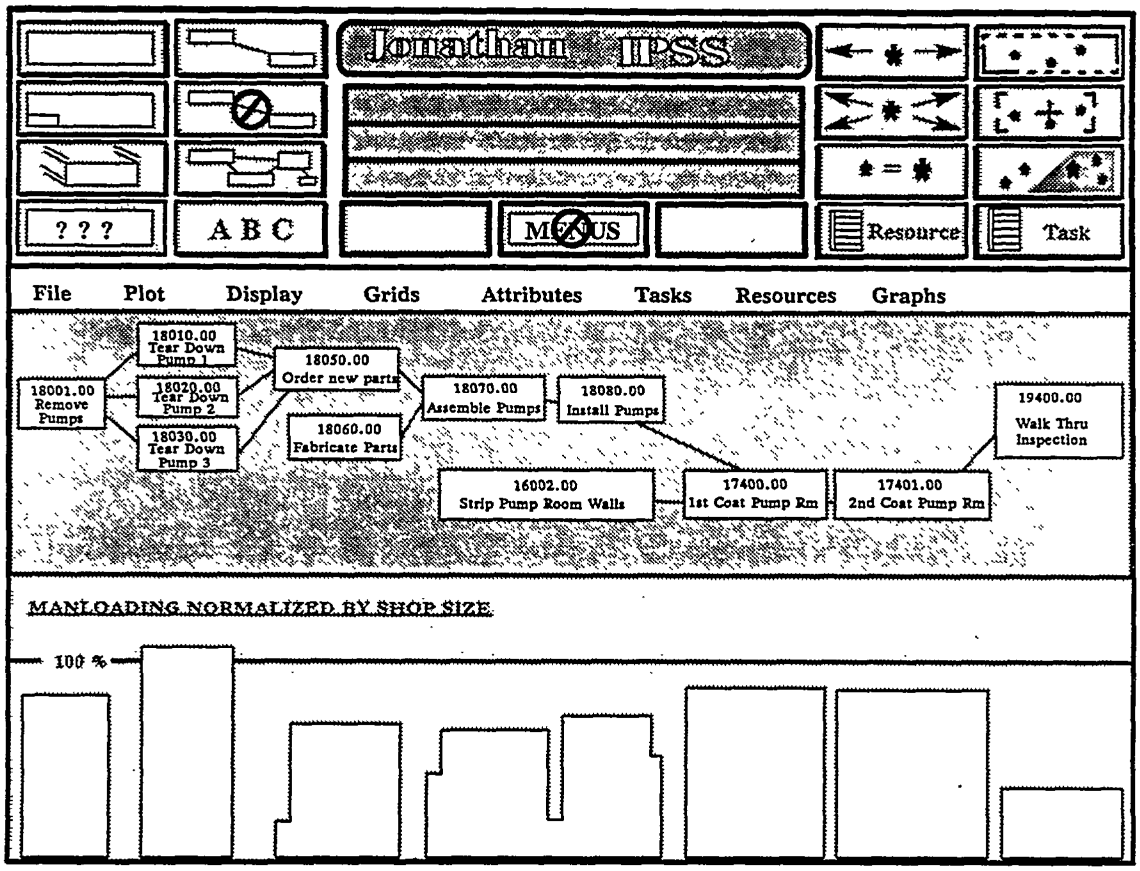

Figure 4 IPSS Manloading Display

Mechanical discipline requirements could demand a rough cut 3" thick gear tooth one day and an intricately shaped, 16 gauge, flattened piece of duct work the next.

Second, corporate facilities and resources are physically separated making communication difficult. If network links between the various nodes are subject to failure, vitally needed data becomes inaccessible.

Third, schedules are critical because of the restricted Availabilities. This translates into high reliability and accuracy requirements. Lost, uncut or incorrect parts can cause delays impacting not only the crew working the job, but also the crew scheduled to follow on the job. Nothing is more disastrous than burn files stuck on the engineering mainframe system because a data link is down.

Finally, the short lead times necessary to handle the repair items, the remaking of parts that were designed wrong or those ruined during fabrication require a system that is streamlined. The fewer manual interventions that are required and the more automated the process can be, the quicker the overall turnaround time can become.

Hardware Considerations

In considering CAD/CAM hardware, several points are important Foremost is compatibility with existing or planned mainfarmes, microcomputers. terminals, work stations, plotters and printers. In our case, there existed multiple workstations capable of running CAD applications and one capable of running Computer Aided Manufacturing (CAM) programs. Rather than purchase additional workstations, the corporation opted to create the part geometry and to nest from within the CAD applications programs. The-se two steps represent the majority of time spent in generating numerical control (NC) data and workstations dedicated-to these functions can easily be adjusted to meet fluctuating production needs. While part geometry definition in the CAD application was easier than in the CAM application, some features were sacrificed by performing part nesting from a two-dimensional CAD environment. This was offset by limited plotting capabilities offered in the CAM program.

Another area offering considerable flexibility was that of interfacing the engineering mainframe and the NC Burning Machine. The simplest interface was a manual interface. Programs would then have been loaded into the burning machine form either the 8" floppy diskette or from the paper-tape reader. A major disadvantage to this mode of operation was the slow turnaround time. A second method considered was a direct interface, where modems or multiplexers would be placed at each end of the communication link and programs transferred over telephone lines with operators at each end coordinating the effort.

A third method, and the one utilized in the present system, is the indirect interface. An intermediate processor was inserted between the mainframe and the burning machine, in this case a Texas Instruments minicomputer. Programs are sent from the mainframe to the minicomputer, where they are stored on the disk. Transfer to the burning machine is over a direct line by a single operator. Whatever the chosen method of interfacing, one thing that is certain is that there must be some form of backup in the event of a mechanical or electronic failure of any component. To this end, the system must be configured with some redundancy in mind. A final consideration concerning hardware requirements is the need to design the system allowing room for growth. Added productivity will surely enhance demand.

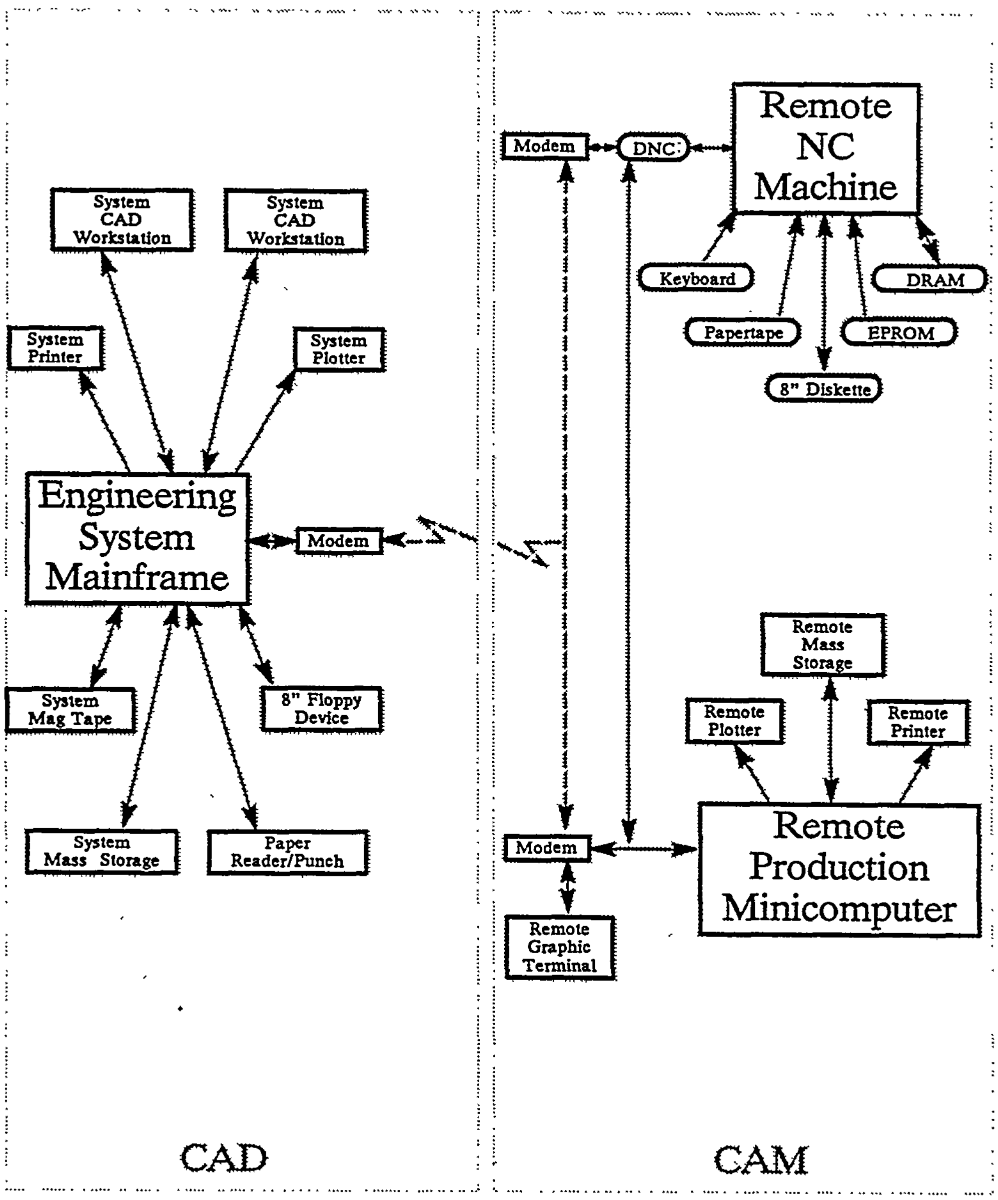

Figure 5 CAD/CAM Network

Software Considerations

In selecting the software and the utilities to be used on the system, training requirements were a foremost consideration. While the corporation had many users trained in CAD, there were **no users trained** in CAM. The existent workload of NC programming was handled by two people, one strictly defining geometry and nesting, the other tool pathing and coordinating the efforts of the various groups within the company. Development of macros within both the CAD and CAM applications helped to bring new users quickly up to speed They further helped to guarantee the quality of the final product by streamlining the number of commands needed to be issued by the operator. hence, reducing the potential for error.

Cycle times were shortened by the use of system dependent "command" programs and file naming conventions. Because it was necessary to repcatedly switch from one program to the next, "command" streams that supplied the necessary startup prompts, built the input and output files, loaded the necessary macro files and programmed the terminals special function keys had a tremendous impact on productivity.

The last software item to be considered was the post processor. Third party CAM packages were offered with two options pertaining to post processors. One was to have a custom program developed speciftically for the output NC machine. The other alternative was to develop a more flexible program allowing the user to mold the output to match the machine. While the custom processor was cheaper, it offered no flexibility to the user, and any changes to its function had to be made through software revisions.

It is important to accurately specify the functionality of the post processor. paying close attention to the features and functions of the target machine tool. Failing to do this could result in the need for extensive file editing to rectify the problems. This interjects another possible source of error and increases the process turnaround time.

Phase	Part Database Fields . . .	
ID CAM PART PHASE	Job Number	6
	Alt Number	6
	Spec Item Number	8
	Work Element Number	6
	Drawing Number	3
	Drawing Revision	1
	Detail Number	3
	Kit Number	5
	Bom Number	3
	Part ID	3
	Quantity	4
	Material Reference Flag	1
	Material Type/Spec or Seagull Number	17
	Part Length	3
	Part Width	3
	Part Thickness	3
DEFINE GEOMETRY PHASE	**Half Flag**	1
	Modified Geometry Flag	1
	Interior Cutout Flag	1
	Marking Flag	1
	Layout Time	3
	Date Completed	8
POST NEST UPDATE PHASE	**Date Nested**	8
	Nest Number	4
	Process	1
	Description	25
		128

Nested Plate Database Fields . . .	
Job Number	6
Nest Number	4
Plate Length	3
Plate Width	3
Plate Thickness	3
Material Reference Flag	1
Material Type Spec or Seagull Number	17
Purchase Order Number	10
Date Nested	8
Estimated Bum Time	3
Utilization Factor	5
Work Element Number	6
Date Burned	8
Actual Bum Time	3
	80

Drop Plate Database Fields . . .	
Job Number	6
Nest Number	4
Plate Length	3
Plate Width	3
Plate Thickness	3
Material Reference Flag	1
or Material Type/Spec	
Seagull Number	17
Purchase Order Number	10
	47

Figure 6 CNC Data Sheet

Database Considerations

The last topic for this part of the paper deals with the aspects of managing the information created, used, modified and referenced throughout the system. A simple job can generate hundreds of parts. a more complicated job, thousands. It is imperative that the user able. able to determine the parts affected by a drawing revision, or a list of nests containing the parts to kit 804. or the status of nest 123. While manual tracking of this information is possible, it is not very practical. The flexibility built into the corporate Engineered Management System (EMS) allowed it to be adapted to the tracking of parts, nests and drop plates throughout the system and in generating reports summarizing the developed CAD/CAM work.

Operative Hardware

As mentioned earlier, three major hardware components comprise the corporate CAD/CAM system (Figure 5). At the time of this writing, three PRIME computers were networked - the model 9955 at the Engineering center, the model 2550 at the CAD drafting site and the model 9955 at the corporate business offices. Presently, Digital Equipment Corporation VAX computers are networked to the CAD/CAM system. Data files produced by application programs on the various nodes in the network are readily accessible by any user on the system. The mainframes support multiple terminals, graphic work stations, CALCOMP and Hewlett Packard plotters and printers for inputting and outputting data. Connected to the computers are approximately 1500 megabytes of online mass storage. These hard disk

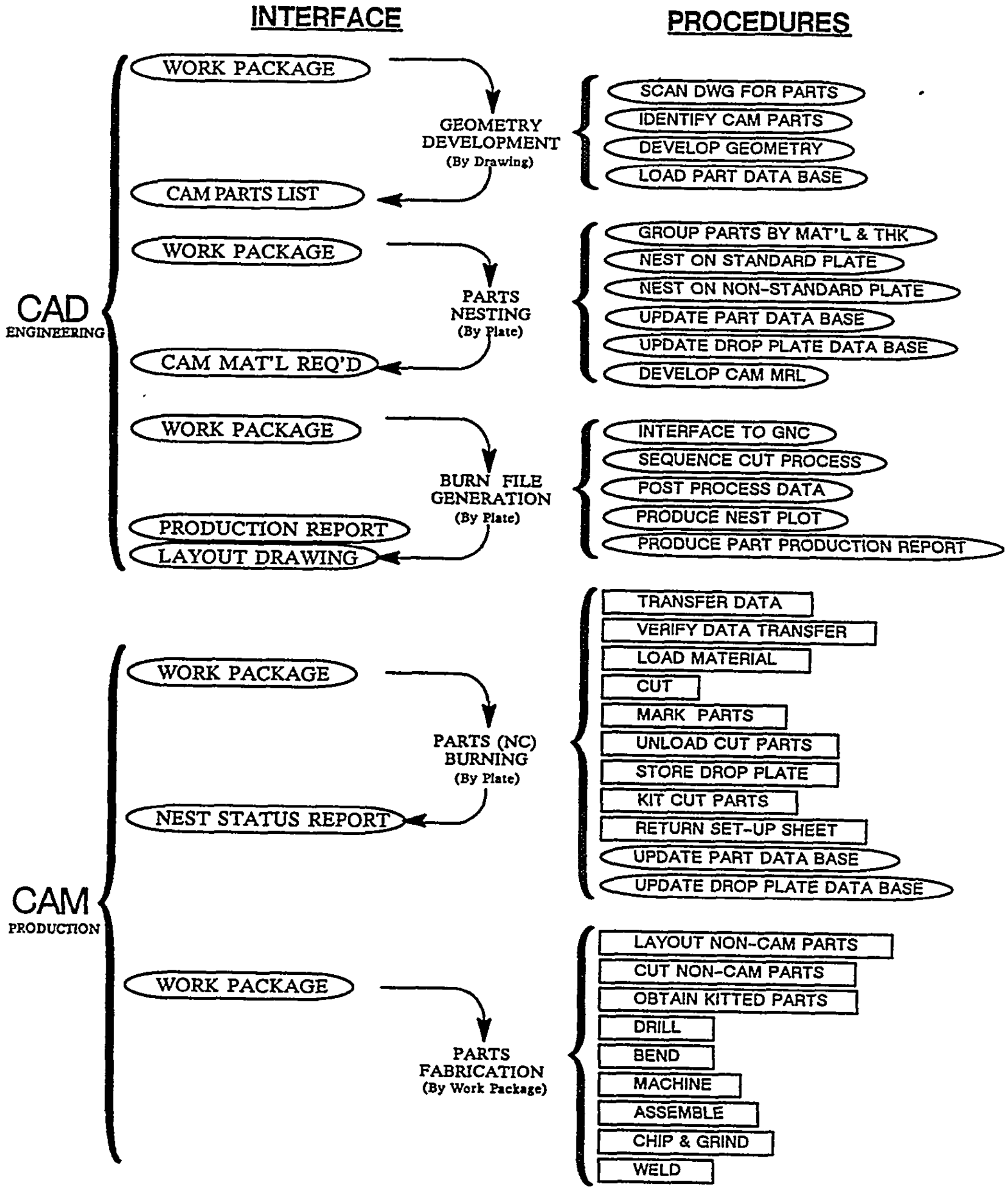

Figure 7 CAD/CAM Operations

files contain the application programs, operating systems and job data files. In addition, a nine-track magnetic tape unit is also attached and used for backups, archiving and cross-system data transfers.

Intermediate components in the form of Texas Instruments microcomputers add considerable system versatility. Equipped with 512K of RAM, color graphic monitors, serial and parallel communication ports, 10 megabyte fixed Winchester discs, 5-l/4" floppy disks, numerical co-processors and dot matrix graphic printers, they can operate as stand alone distributed systems enabling pre and post-processing of the data form the engineering system. They can also provide local word processing features or simply function as "intelligent" terminals with file uploading and downloading capabilities.

At the other end of the system is the LINDE CM-350 Burning Machine. Controlled by a UCNC-7/8 microprocessor and outfitted with an Anderson water table, it is capable of plasma or oxy/fuel cutting under control of programs conforming to the EIA Word Address format. Data entry can be accomplished from a variety of sources i.e., the keyboard, an 8" floppy diskette, an ASII paper-tape, Direct Numerical Control (DNC), Dynamic Random Access Memory (DRAM) or Erasable, Programmable Read-Only Memory (EPROM). Once transmitted to the machine, programs can be locally stored on either the 8" diskette or. in the DRAM by the operator. A built in line editor is available for previewing and/or modifying the data, With a DNC link, previously stored programs can be retrieved and transmitted back over the communication link to the host computer.

Operative Software

Tying the hardware together is the application software. Neglecting the various system editors, there are five major software programs required to keep the system functioning. The entire process starts with MEDUSA which is used extensively for geometry development, nesting, program reports and two -dimensional drawings, Other utilities such as the three-dimensional modeller, the viewer and the shrinker provide the

LINDE CM-350 BURNING MACHINE LIMITATIONS

	MAX	MIN
PLATE SIZE		
Width	10 ft	none
Length	*40 ft*	*8 in*
PLATE THICKNESS		
Aluminum	*2 in*	*1/8 in*
Stainless Steel	*2 in*	*1/8 in*
Steel (gas)	*6 in*	*1/8 in*
Steel (Plasma)	*2 in*	*l/8 in*

SPECIAL CONSIDERATIONS

Bevel Cuts	not programmable at present time+
Multiple Cuts	limited to gas only - 2 torches
Surface Prep	plate must be free of multiple coats of paint plate must be free of built-up rust deposits the better the prep, the better the cut"
Laminate Plates	not acceptable
Expanded Metal	not programmable (manual jog, straight cuts only)
Grating	not programmable (manual jog, straight cuts only)
Structural Shapes	not programmable
Pipe	not programmable

NOTES

These limitations are flexible. For special applications contact the Engineering Department (Bruce Carr).

• Verification required.
+ Straight line bevels may be done manually.

Figure 8 Linde CM-350 Burning Machine Capacities

capability of generating meaningful visual representations of complex assemblies of parts when necessary.

The process continues with EMS. This application, developed in-house, provides for the creation and maintenance of relational databases to track labor and material associated with work elements. EMS was extended to include additional fields to properly track parts, nest and drop plate data (Figure 6). An associated variable reporting module allows EMS users to custom tailor outputs to suit their particular needs. Selection of entries can be made against user defined limits so that it is possible to select only parts with lengths less than 48 inches, parts completed after a certain date, parts associated with a particular detail on a specific drawing, etc.

Geometry definition, part nesting and cut sequencing are performed in GNC, the third major software component. In our implementation however, only cut sequencing (tool pathing) is done in this program. Part geometry and nest layouts are automatically loaded into GNC from entities present on MEDUSA drawing sheets via a direct transfer. The binary, "generic" data tile containing the "Cutter Location (CL) data" produced for sequenced nests requires messaging into a format suitable for the target NC machine. This messaging is done by CAMPOST the fourth software component. It is a custom developed post-processor that converts the CL data into the LINDE EIA Word Address format

The fifth software component in the chain is XTALK, which enables the Texas Instrument minicomputers to exchange data tiles with the mainframes and the LINDE CM-350 Burning Machine via a standard RS-232 interface.

CAD/CAM OPERATIONS

CAD/CAM fabrication at the corporation involves three. CAD operations and two CAM operations (Figure 7). Each of these operations involves several stages that are now considered in detail.

CAD Geometrv Development

CAD/CAM operations begin with a consideration of overall material requirements. For a PMA, this entails both modernization and repair actions. Modernization material requirements by and large are specified on the applicable Ship Installation Drawings (SlDs) prepared for the proposed ship alterations. Material requirements for the repairs associated with a PMA are developed from Design Service Request (DSR) sketches or from technical manuals that accompany the repair or renewal of specific machinery and its surrounding structure. DSR sketches either define machinery foundations or the geometry of substitute parts. In either case, a drawing number of record identifies the DSR for both Navy review purposes as well as for reference entry into approved Navy specifications.

As each SID or DSR is completed and approved, the first CAD/CAM operation - CAD Geometry Development - begins. Production engineers review drawings from the viewpoint of CAM burning machine capacities and capabilities (Figure 8) in order to identify candidates for CAM fabrication. Plate size and thickness considerations are paramount for structural CAM entities. Likewise, minimum cut radius and machining speed considerations pertain to most repair part

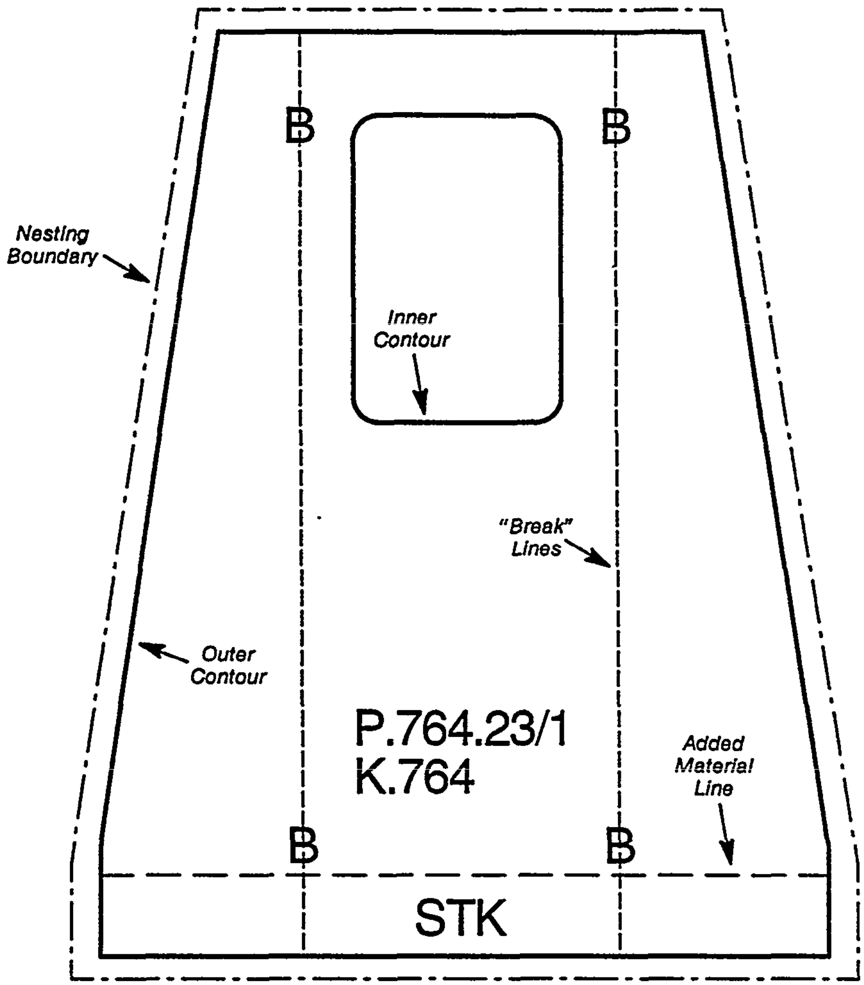

Figure 9 CAD Part Geometry

CAM identifications.

Once the possibility of CAM is indicated for a part, it is entered into the CAM Part Geometry database. The CAD application program .is then used to create the individual part geometries. Numerical lofting techniques are employed to develop the planar outlines for each part. Special consideration must be given to such things as flanged parts, ductwork, rolled plates and added material for shipyard fit-ups. Each unique piece-part is then stored as a "symbol" (Figure 9), within a pre-defined file structure, for later use in the nesting phase. An added benefit of this file naming convention is the ability to reference "standard" parts. In this way, geometry can be re-used and lofting time reduced.

CAD Parts Nesting

The second operation in the CAD/CAM process is one peculiar to CAD/CAM - viz., Parts Nesting. Since parts having multiple thicknesses and material types are created in the CAD Geometry Development phase, the consolidation of these parts - enabling quantity buys of steel plate - requires two phases. The first is accomplished through the use of the selection and sorting features of the EMS part database. The second phase - Parts Nesting - is a graphical exercise within the CAD application program.

To aid in parts nesting, a variable report from EMS is produced (Figure 10). The first field in the output identifies the applicable drawing (SID or DSR) that pertains to the Job. The next field is the thickness of the part in sixteenths of an inch. The immediate aspect of this thickness listing is, of course, the possibility of combining like requirements into a composite. plate buy. The next fields in the output are the CAD Part Number - which is composed of the (last) three digits of the drawing number - and the piece/part number designation from the applicable drawing's Bill of Material. The next field is the drawing detail upon which the CAD part is specified. Quantity. material specification, length and width data (both in inches) comprise the next fields in the report A calculation involving these entities produces the area (in square inches) of the plate (of particular thickness) needed to satisfy the material requirement. The field is a textual designation of the part that aids in subsequent identification for production purposes. As is evident from this listing, a total compilation of particular plate requirements from all drawings pertaining to a job can be readily determined.

Nesting is accomplished by placing CAD part geometries - available from CAD drawing detail files - upon various sheet patterns while maintaining considerations regarding minimization of excess material and attention to the peculiarities of CAM parts generation. The first consideration is automated by the computer which generates nesting

Dec 7, 1986 time: 17:09 J O N A T H A N C O R P O R A T I O N PAGE 0001

C A M P a r t G e o m e t r y L i s t - J o b 1 8 8 8

- (VReport for JONATHAN internal use only) -

dwg	thickness	part no.	detail	quantity	length	width	area	description
002	5	P.002.01/08	5-A	175	9	9	98.437	9X9 BKTS (3X3 LEGS)
002	5	P.002.01/09	5-B	182	9	9	102.375	9X9 BKTS (3X1 LEGS)
002	5	P.002.01/04	6-A	24	24	7	28.000	INBD BTM CHKS FR 4-18
002	5	P.002.01/05	6-A	24	20	7	23.333	OTBD BTM CHKS FR 4-18
002	5	P.002.01/06	8-B	24	24	8	24.000	INBD DK CHKS FR 4-18
002	5	P.002.01/07	8-B	24	20	8	20.000	OTBD DK CHKS FR 4-18
002	5	P.002.01/10	6-D	30	25	9	48.875	TBHD BKTS @ SIDESHELL
002	5	P.002.01/11	8-C	34	29	9	81.825	TBHD BKTS @ LBHD
002	5	P.002.01/15	3-B	12	20	7	11.666	BTM CHK PLS @ FR 2
002	5	P.002.01/16	4-D	18	20	7	15.555	BTM CHK PLS @ FR 1
002	5	P.002.01/16	4-D	4	37	13	13.381	LBHD&SSWEBS@FR 1
002	5	P.002.01/03	4-A	24	79	19	250.188	LBHD TRANS WEBS FR 4-18
002	5	P.002.01/17	4-C	2	75	13	13.541	LBHD VERT WEBS @ FR 2
002	5	P.002.01/13	3-B	2	87	78	94.250	WT BHD PL @ FR 2-P/S
002	5	P.002.01/12	2-B	3	98	13	26.000	TBHD VERT TRUSS GDR-FR 3
002	5	P.002.01/14	3-B	2	98	78	104.000	WT BHD PL @ FR 18-P/S
				582**			933.184 **	
002	8	P.002.09/06	2-C	21	15	1 0	21.875	BTM & TRN'SM LONG'L BKTS
002	8	P.002.09/07	2-C	21	14	9	18.375	BTM LONG'L BKTS @ KNUCKLE
002	8	P.002.09/01	7-C	16	24	22	58.888	SPUD SUP'T BKTS - ABV DK
002	6	P.002.09/04	4-C	18	28	1 5	43.333	OTBD DK STF'NRS - DK & BTM
002	8	P.002.09/08	4-C	18	28	8	17.333	INBD DK STF'NRS - DK & BTM
002	6	P.002.09/02	7-C	18	30	25	83.333	TRANS SPUD BKTS - BLW DK
002	8	P.002.09/03	4-C	16	31	30	103.333	LONGL SPUD BKTS - BLW DK
002	8	P.002.09/05	4-c	32	30	6	40.000	LONGL STF'NRS - DK & BTM
				154 **			366.246 **	

Figure 10 CAD Part Geometry List

boundaries (Figure 10). As each part is nested by a CAD engineering technician, the status is updated in the parts database to reflect the operation. In thisi way, the completion of the nesting phase is readily verified when all of the piece parts in the CAM Parts File are associated with all of the nests in the CAM Nesting File. At this point, a consolidated Material Requirements List is, generated (Figure 11) and a cost effective, integrated plate purchase is then made by procurement personnel.

The second consideration in CAM Part generation concerns the peculiarities associated with the operation of the burning machine. The plasma process only cuts cleanly when moving in one direction. Hence, machine operations for inside cuts must reflect the proper orientation of the arc - a situation that is specified in nesting by a skilled CAD engineering technician.

Associated with nesting is the concept of "kitting". As it stands, combinations of CAM parts are provided to production in kits to facilitate later fabrication. Of course, a kit can contain several CAM parts that are generated on several different nests! Again, skilled CAD engineering technicians determine the contents of each kit and reflect the necessary correlations between kit numbers, nest numbers and part numbers. A regular check of this database assures that the kit-nest-part number correlations are preserved correctly and that indeed kits required to accomplish a particular Navy work specification (Figure 12) are identified.

CAD Bum File Generation

Once nesting and kitting operations are complete, a "Bum File" is computer generated to provide the necessary machine instructions to cut out the required parts. The Burn File takes into account machine capabilties, plate thickness and material constituency and produces a record like that shown in Figure 13. Depending upon a combination of factors (plate thickness, material, burning machine torch selection), operating speeds (inches-per-minute @PM)) and operational mode data are combined to produce a Machining Time profile record (Figure 14) that enables machine usage factors to be gathered for audit purposes. Although a "Paper Tape" output is mentioned here, its only significance is with respect to the buffer size of the target NC machine.

For every sequence of CAD/CAM operations on a plate size, a CAM Production Record (Figure 1.5) is computer generated to aid the CAM machine operator in producing and kitting the CAM parts associated with a particular plate.

CAM Parts (NC) Burning

As the production schedule dictates, the burn files are executed on the NC machine to produce physical parts. It is to be noted that the CAM Production Record (Figure 15) provides for feedback entry of tool path offset (kerf) and machine feed rate (feed). Both of these values are used to determine the accuracy and efficiency of the process. By

Jan 3, 1987 time: 11:48 JONATHAN CORPORATION PAGE 0001

CAM MATERIAL REQUIREMENTS JOB 1588

- (VReport for JONATHAN internal use only) -

nest	material type	thickness	length	width	date nested
N.010	AL/QQ-A-2501/9	6	240	64	8/26/65
N.011	MATL PUR CHANGE				
N.012	SS/QQ-S-766	8	48	48	8/27/85
N.013	AL/QQ-A-2501/9	6	240	64	9/11/65
N.014	AL/QQ-A-2501/9	6	240	64	8/28/85
N.015	ALQQ-A-250/19	6	240	64	8/28/85
N.016	OS/MIL-S-66298	4	240	48	9/06/85
N.017	AL/ASTM-B-209	12	240	48	9/17/85
N.018	MATL PUR CHANGE				
N.019	OS/MIL-S-22698	4	46	48	9/06/85
N.020	OS/MIL-S-22698	6	240	96	
N.021	OS/MIL-S-22698	a	96	48	
N.022	MATL PUR CHANGE				
N.023	HS/MIL-S-24645	8	120	72	
N.024	HS/MIL-S-24645	a	120	72	
N.025	AL/QQ-A-250/19	10	120	96	9/16/85
N.026	ALQQ-A-250/19	5	120	96	9/I6/85

Figure 11 CAM Material Requirements

monitoring these parameters, engineering personnel can retain control of the process and reduce the decisions that need to be made by production personnel.

CAM Parts Fabrication

The CAD/CAM process is finalized with the ultimate fabrication of shipboard parts. This fabrication is facilitated by the development of computer generated assembly sketches and production work packages. The assembly sketches illustrate the joining of kit parts while the work packages insure that all proper welding procedures and quality control (QC) actions are known and followed at the shipyard. Additionally, time estimates for the labor involved in each of the associated actions (drill, bend, weld, chip & grind, etc.) is recorded so that production labor costs can be related to a finished CAD/CAM entity. A review of the hours expended on the tasks versus those planned for the task provides a ready measure of the cost efficiency of the production.

BUSINESS IMPACTS OF CAD/CAM

The impact of an operative CAD/CAM system in the marine environment is significant A review of this impact on several shipyard operations is now presented.

Engineering Impact

One of the most significant CAD/CAM changes impacted the engineering groups due to the added design responsibilities placed upon them. Whereas before the “final” product was a design drawing, now it is an actual cut part. The responsibility of assuring that the part produced indeed agrees with the design is lifted from the production work force and placed directly where it belongs - on Engineering. This “accountability” has had a positive affect on the quality of the design. Now information previously omitted or determined incorrectly is discovered by CAM production engineers working side by side with design engineers.

Proper scheduling of part generation can identify deficiencies early enough to allow modifications to the drawings - before release - thereby eliminating a time consuming revision process. Another point consider is the time savings and design simplification that is attained by standardization. Geometries can be re-used. Warehousing overhead can be reduced and product quality improved by establishing and maintaining design- and drafting standards. Raving the abilty to generate NC machine programs from within the engineering environment can also open up a whole new market for a company specializing in design services.

With proper training, guidance and experience., design engineers can learn to generate their own parts and be freed of the drudgery and inefficiency of detailing. Their time and effort can be better spent preparing sketches identifying the parts comprising and assembly. The sheets of drawings previously sent to the shop floor can be replaced with one or two assembly drawings that identify the parts needed and depict their orientation and relationship to one and other.

Planning Impact

Moving into the area of planning one immediately recognizes the existence of limitations. Not all parts are suitable for CAM - some are too small and others are too big. Production engineers must be aware of these limitations in order to properly estimate and direct the work flow. Major assemblies may have a mixture of CAM parts. piping. tubing, tees, angles and non-CAM parts and proper routing of individual components must be assured for smooth work flow. Production engineers must work closely with the design engineers and vice versa. Production planning is a step closer to actual fabrication and has the potential for exposing weaknesses in a design overlooked in the previous steps.

An important step in insuring that “cost savings” and schedule adherence are attributable to CAD/CAM is the push for pre-fabrication of structural assemblies. Just as pumps, motors and deck machinery are procured to be at pierside at the start of an availability, so too, must be the case of “structural” CAM parts and assemblies. With proper engineering and management involvement, this can be a realizable goal.

Finally, the concept of a “kit” is introduced in order to group parts after cutting. Whereas before a shipfitter received all the material for an assembly and personally laid out and cut the individual parts as needed. now an operator at a remote site will cut parts that may be used by four or five different shipfitters at four or five different periods in the availability.

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CAM PART REPORT JOB 1588

- (VReport for JONATHAN internal use only) -

spec	kit	part no.	nest number	description
57390001	K.595	P.595.6/1	N.000	PLATE
57390001	K.595	P.595.8/1	N.OOO	LOWER DOOR WT
57390001	K.622	P.622.1/13	N.000	FRAME
57390001	K.826	P.826.1/1	N.O1O	PLATFORM DK
57390001	K.826	P.826.1/3	N.013	CLOSED FR FULL
57390001	K.826	P.826.1/4	N.013	CLOSED FR HALF
57390001	K.826	P.826.1/5	N.014	PLATFORM BOTTOM
57390001	K.826	P.826.1/7	N.015	OPEN FR
57390001	K.826	P.826.2/1	N.025	SIDE
57390001	K.826	P.826.2/2	N.026	SIDE
57390001	K.826	P.826.2/3	N.026	CENTER FRAME ENDS
57390001	K.826	P.826.2/4	N.026	CENTER FRAME MIDDLE
57390001	K.826	P.826.2/5	N.026	STIFFENER
57390001	K.826	P.826.3/1	N.012	COLLAR
57390001	K.827	P.827.1/1	N.016	LOWER SLIDING DOOR
57390001	K.827	P.827.1/3	N.016	CHOCK
57390001	K.827	P.827.1/4	N/019	CHOCK
57390001	K.827	P.827.2/1	N.017	UPPER BI-FOLD DOOR
57390001	K.827	P.827.3/1	N.018	LOWER SLIDING DOOR
57390001	K.827	P.827.3/2	N.018	STIFFENER
57390001	K.827	P.827.3/4	N.018	BACK PLATE
57390001	K.827	P.827.7/1	N.000	SIDE PLATE
57390001	K.827	P.827.8/1	N.OOO	GUIDE RAIL

Figure 12 CAM Part Report

Purchasing Impact

Unlike the previous groups, the impact of CAB/CAM on the purchasing department tended to simplify their job. About the only detrimental effect was the loss in flexibility of filling purchase orders. Prior to NC burning, purchasing was given a relatively free hand. For example, if a plate 20’ long was requested and two 10’ long plates were all that could be found, the substitution was made and the shipfitter left to piece the two together at fabrication time. Since engineers worked on one assembly at a time, they identified material for assemblies one piece at a time. If assembly A required a piece of l/2” plate 12” x I2”, that was what was ordered. Later, while planning assembly B, if they found that another 12” x 12” piece of l/2” plate was needed, it was ordered. Purchasing agents, not in a position to judge the proximity of shipfitter A to shipfitter B, had no recourse but to order 2 pieces of 12” x 12’ plate. Meanwhile, purchasing agents were accumulating orders from many engineers, each identifying material requirements in a disjointed, piece-meal fashion.

To carry the scenario a step further, the purchasing agents, after contacting several sources for the material, discovered that most handled stock sizes and charged extra for cutting to non-standard sizes. For thinner plates, 2’ x 4’ is about the smallest stock size carried and the cost differential for the extra 7 sq. ft. per plate would amount to about $35. The end result - 2 sq. ft. needed, 16 sq. ft. delivered. With the implementation of NC part generation and nesting, many of these inefficiencies are avoided. Nesting, which begins after all parts are defined, provides for consolidation and better overall material utilization. The user of standard sizes. readily stocked by either the warehouse or local vendors, eliminates the need for last minute scrambles to find odd sized plates. Lastly, the unused portions of the larger plates can be returned to inventory and re-used at some later time.

Production Impact

The net result of these changes on production is evident in the quality of the final product. The need for excessive grinding to clean up the ragged edges from manual burning is eliminated. Less time is spent re-cutting parts because a worker in the field guessed at a dimension obscured by a blob of grease or lost to a careless spark from a nearby cutting torch. Welding time is reduced due to closer and more uniform fitups. On the negative side, it imposes increases material handling requirements, as cut parts must be temporarily stored in the warehouse and then subsequently delivered to the job site.

In the long run, the level of skip needed in the trades is significantly reduced. The ability to understand and interpret blue prints is no longer a criteria for filling a shipfitter position. Anyone capable of simple assembly possesses most of the skips needed to understand the work to be performed.

Management Impact

What does all this mean to management? It increases the administrative duties that must be performed. People with highly specialized skills ranging from an in-depth knowledge of production methods and practices, to familiarity with computer hardware and software, to an understanding of cutting processes must be strategically placed within the corporation. A tremendous amount of inter-department communication is required to keep the job on track Hence the need for a common operative database (like the one available from EMS) is evident. Most important of all, it is necessary to re-valuate the way you do business to be sure that the system is as productive as possible. In the present case, an enviable PMA record of accomplishment (Figure 16) attests to the efficacy and cost savings of CAB/CAM parts generation.

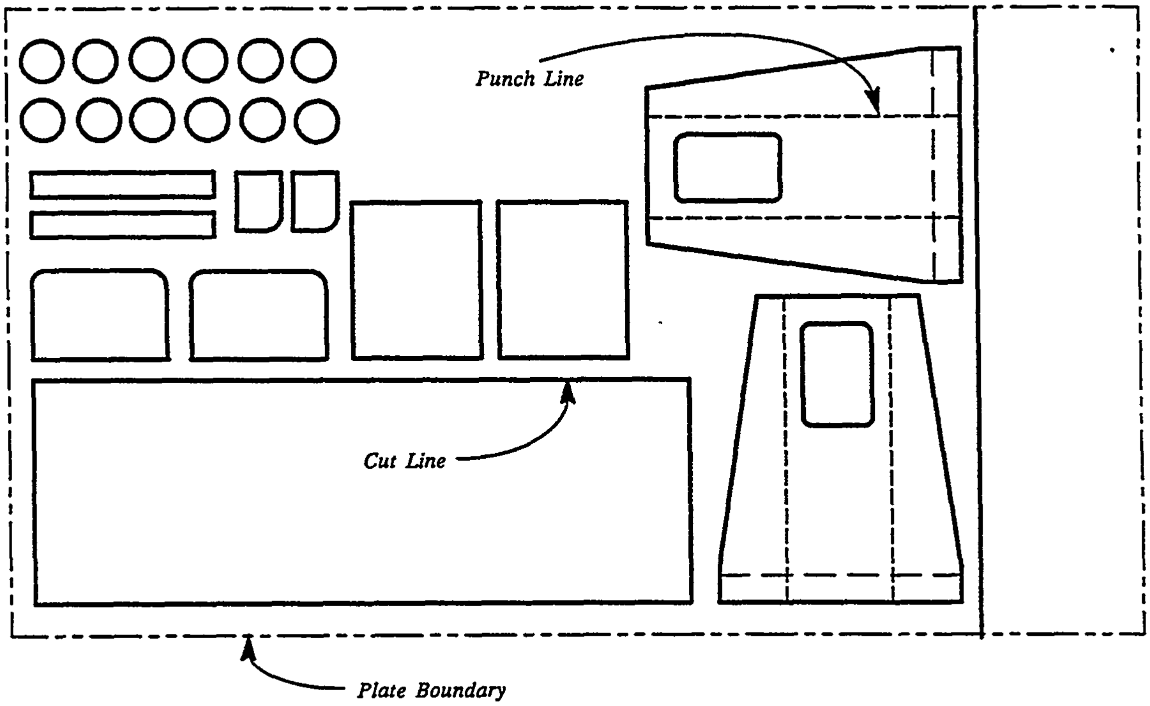


Figure 13 CAD Generated Burn File

C N C S T A T I S T I C S S H E E T

INDEX NUMBER 223.0
SOFTWARE REVISION 1.0

ENTER OUTPUT MEDIA (DISC/TAPE) : DISC
ENTER CLDATA FILENAME : CLD.999
ENTER TAPE FILENAME : N1090999
ENTER PRINT FILENAME : P.999

POST-PROCESSING COMPLETED

TOTAL NUMBER OF TAPE BLOCKS OUTPUT. . 313
LENGTH OF PAPER TAPE OUTPUT. . . . . .37.28 FEET (4,474 characters)

MODE	LENGTH(inches)	RATE(IPM)	TIME(minutes)
RAPID	1421.22	300.0	4.74
CUTTING	1920.07	130.0	14.77
MARKING	0.00	300.0	0.00
SUBTOTAL	3341.30		19.51

14 CYCLE STARTS AT 10.0 SECONDS

ESTIMATED MACHINING TIME . . . . . 21.84 MINUTES

THE FOLLOWING FILES HAVE BEEN CREATED

TAPE FILE N1090999
PRINT FILE P.999

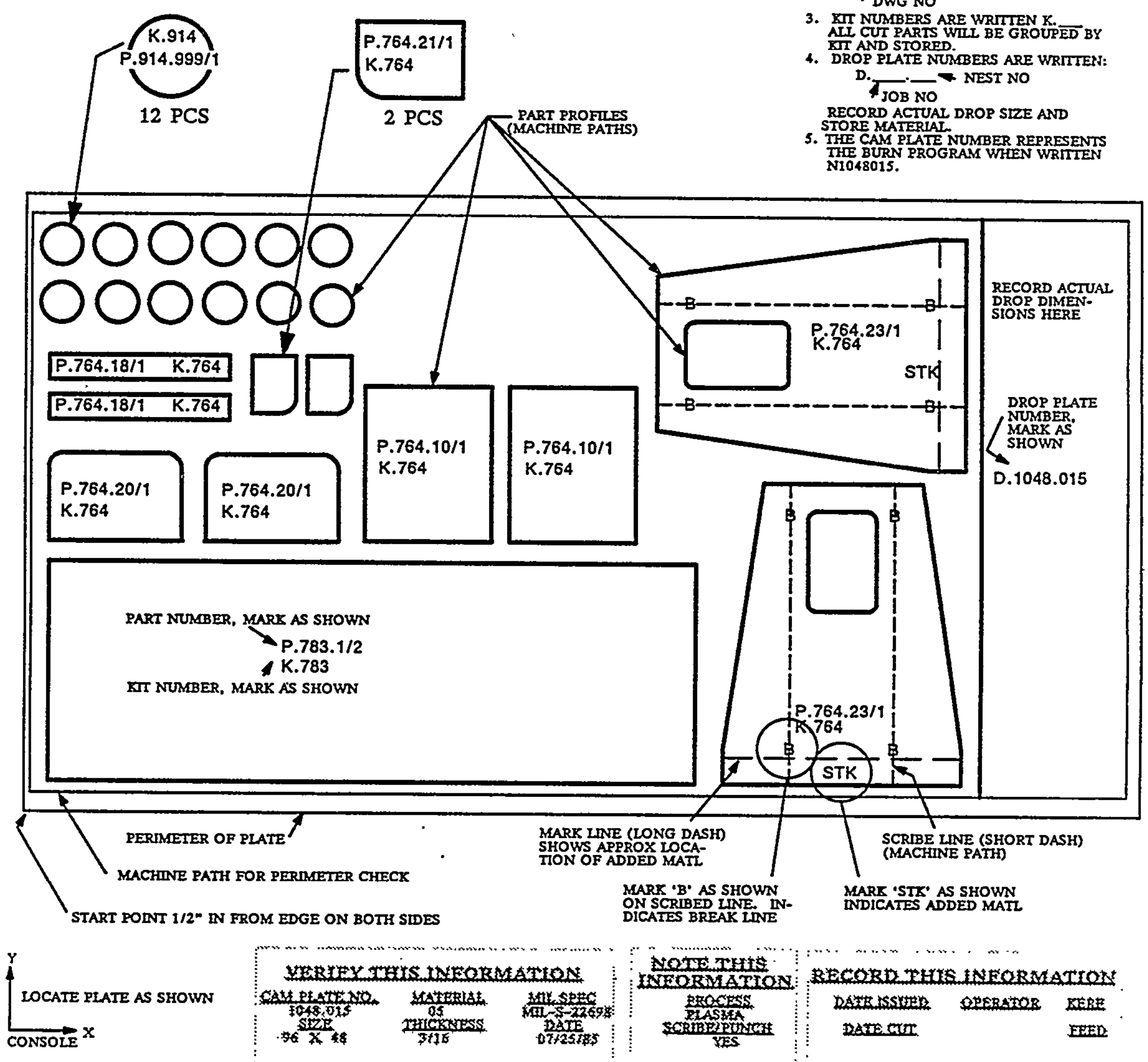
Figure 14 CNC Statistics Sheet

INSTRUCTIONS FOR USING LINDE BURN PROGRAM REPORTS

REV. 7/25/85 B. CARR

GENERAL NOTES

1. RETURN THIS SHEET WITH COMMENTS AND REQUIRED INFO TO ENGINEERING DEPARTMENT.
2. PART NUMBERS ARE WRITTEN :
   P.___._/_ ← DWG PART NO
   ↑ DWG NO
3. KIT NUMBERS ARE WRITTEN K.___
   ALL CUT PARTS WILL BE GROUPED BY KIT AND STORED.
4. DROP PLATE NUMBERS ARE WRITTEN:
   D.____.___ ← NEST NO
   ↑ JOB NO
   RECORD ACTUAL DROP SIZE AND STORE MATERIAL.
5. THE CAM PLATE NUMBER REPRESENTS THE BURN PROGRAM WHEN WRITTEN N1048015.



VERIFY THIS INFORMATION

CAM PLATE NO.	MATERIAL	MIL SPEC
1048.015	05	MIL-S-22698
SIZE	THICKNESS	DATE
96 X 48	3/16	07/25/85

NOTE THIS INFORMATION

PROCESS
PLASMA
SCRIBE/PUNCH
YES

RECORD THIS INFORMATION

DATE ISSUED	OPERATOR	KERF
DATE CUT		FEED

Figure 15 CAM Production Record

PHASED MAINTENANCE RECORD

PMAS	Class	Avg. Grade	Rating
20	AFS	91.20	Outstanding
8	AOR	91.88	Excellent
10	LST	90.79	Excellent

Figure 16 PMA Record of Success

SUMMARY

As the foregoing presentation reveals, the introduction of CAD/CAM into a ship repair program produces profound and fundamental changes. First, business as usual cannot be practiced anymore. To offset the cost of CAD/CAM hardware, real cost savings attributable to better material utilization and more efficient production must be evident. Second, even a small-scale introduction of CAD/CAM into the related engineering and production phases of shipyard practice can indeed produce significant savings - in labor and material. Material products are much more accurate because CAD/CAM technology is able to produce parts with less requirements for subsequent finishing. Hence, labor costs are reduced. Likewise, the practices (not concepts - but practices) of nesting and Kitting insure that materials are optimally combined for both purchasing and production. The final lesson-to-be-learned from this CAD/CAM experience is the large and varied dedication of people resources necessary to effect installation. Job viewpoints as well as actual personnel may have to change to insure that a CAD/CAM operation is fully effective. Hence. the interest and involvement of management - at every level of manufacturing - is necessary to make CAD/CAM a real FABRICATION process.

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Plister Hotel, Milwaukee, Wisconsin, August 21-24, 1990

Development of Design and Fabrication Method of Thin Steel Plate Structure and its Application to a Passenger Ship

7A-1

Tomoya Hamasaki, Visitor, Ishikawajima-Harima, Heavy Industries Co., Ltd.

ABSTRACT

Ishikawajima-Harima Heavy Industries Co, Ltd., (IHI), was awarded a contract to build a cruise passenger ship which had a superstructure with 4.5mm thick steel plate decks. Since the first time application of 4.5mm to the hull structure was expected to cause a lot of troubles in conjunction with plate distortion, an effort was made to seek and establish the most appropriate standards of design and methods for thin steel plate structure. Structural design and construction methods were carefully reviewed, selected, tested and applied to the ship, and thereby they were verified throughout the actual construction processes. Successful results were obtained from both quality and cost stand points.

INTRODUCTION

In a passenger ship, particularly in its superstructure, a great deal of thin steel plate is applied in order to maintain the ship gravity point as low as possible against its height and thereby to assure a high degree of ship stability. The application of thin steel plates, however, has very significant impact on the degree of distortion and vibration of the structure, both of which could potentially lead a passenger ship to serious quality deterioration. The annoying behavior of thin steel plate can easily destroy the comfortableness of a completed ship, which is attained by having the least vibration, least noise and most admirable appearance of every portion in sight, none of which is allowed to be sacrificed. On the other hand, reduction of fairing work on the thin steel plate structure is always a big struggle for the production department for saving cost and adhering to schedules, the latter of which has a particularly significant impact on painting and outfitting. Therefore, establishing a method to control the behavior of thin steel plates is one of the most essential challenges, both in quality and cost standpoints, for the shipyard which is building a passenger ship.

Although there are many reports regarding the method of thin steel plate processing, each contributing to the improvement of the method, it can also be said that definite conclusions in the cases of 6mm and thinner are unlikely to be obtained.

The cruise passenger ship in question had a superstructure with 4.5mm thick steel plate decks. It was decided to take an advantage of the opportunity to seek and establish the most appropriate standards of design and methods of handling for thin steel plate structure. The primary focus was on minimizing plate distortion with least expenditure possible.

SHIP SPECIFICATIONS

Figure l-a presents an elevation view and figure l-b a typical section of the ship.

The ship is a Japanese shipping company owned oceangoing cruise passenger ship with the classification of NK, Nippon Kaiji Kyokai, and JG, Japanese Government. The principal specifications of the ship are :

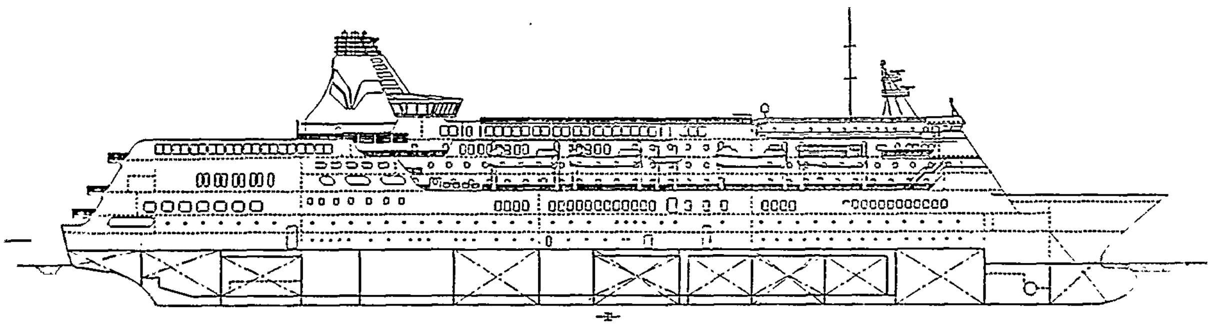


FIGURE l-a. ELEVATION VIEW

Type	Cruise ship
Tonnage	23,000GT, 3,000DWT
Length	175m (574ft)
Beam	24.0m (79ft)
Draft	6.5mm (2lft)
Decks	8
Cruising miles	7,000 n. miles
Main engines	9,270ps IHI-12PC26V x 2
Nav. speed	21 knots
Passengers	606
Crews	120

The building contract was awarded in January, 1989, the fabrication started in July, 1989, and the keel was laid in November, 1989. The ship was launched into the water in January, 1990, and is scheduled to be delivered in July, 1990. The scheduled duration time between the fabrication start and the delivery is 12 months.

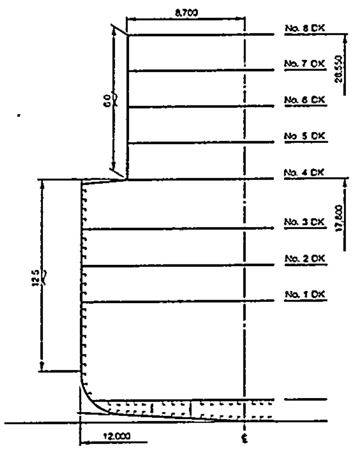


FIGURE l-b. TYPICAL SECTION (IN MM)

DESIGN AND METHODS APPLIED

Figure 2 shows the general approaching scheme that defines areas and matters to be assured in order to attain the least distortion regardless of plate thickness.

In the figure, items in the double boxes are considered to be specially reviewed and improved for the case of 4.5mm superstructure of the ship. Each item was first reviewed empirically at design and planning stages. Experiments were conducted on a case by case basis before the final settlement of design, construction methods and tools/facility applications. The outcome of highlighted design and method applications were monitored closely at each construction process.

A special task force consisting of design and production engineers was formed for this project.

1. STRUCTURE

(1) Block joint

It is widely known that close arrangement of a beam to a block joint will have a good effect on suppressing plate distortion caused by heat of welding at erection. The practical methods to achieve this are summarized:

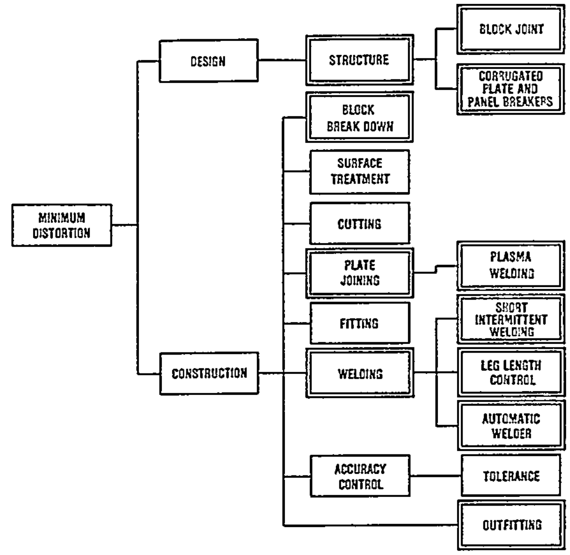


FIGURE 2. APPROACHING SCHEME

a) Locate butt joints where a deck beam runs right underneath.

b) Fit a thick chill plate, 50mm x 22mm, underneath the butt joint, which can also provide counter-distortion restrictions.

c) Locate a beam as close to the joint as possible.

Each one of those methods was carefully reviewed and evaluated considering:

1) The superstructure, in this case, is to stand for longitudinal bending stress equivalent to 80% of that loads on #4 deck.

2) Minimization of hull weight for ship stability assurance.

Methods a) and b) among the above are determined to be applied after experimentations which verified their advantages. Figure 3 shows the sketches of them.

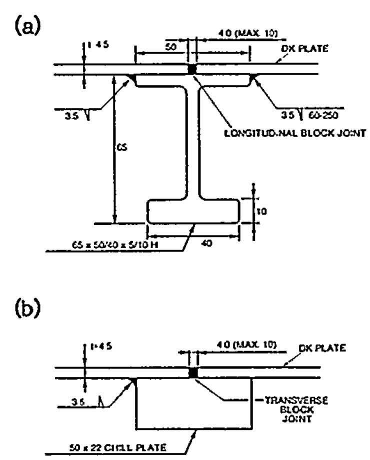


FIGURE 3. BLOCK JOINTING METHOD (IN MM)

Longitudinal joint - The method a) was applied for longitudinal joint. “H” beam was used for a longitudinal beam that runs right underneath joint.

Sectional demensions of the “H” beam were strictly specified in order to maintain the required bending and sheering regidity without weight increase or beam height increase. Dimensions specified were 65mm x 50mm/40mm x 5mm/l0mm, while dimensions of an ordinary longitudinal beam were 65mm x 65mm x 6mm.

Unavailability of standard “H" beam that met these specifications resulted in a joint effort with a steel manufacturer. It was not very long until obtaining the NK approval of the new product.

Figure 4 shows the jointing method of “H” beams at transverse joint.

Transverse joint - Method b) combined with c) was applied for transverse joints. Figure 5 illustrates a typical application of the method. The block joint was set 350mm off a transverse beam on the preceding block. Flat bars were installed 350mm off the joint on the following block.

An alternative method a) was eliminated in the case of transverse joints because of the tremendous increase of additional brackets which hold longitudinal beams on both sides of a transverse beam, figure 6.

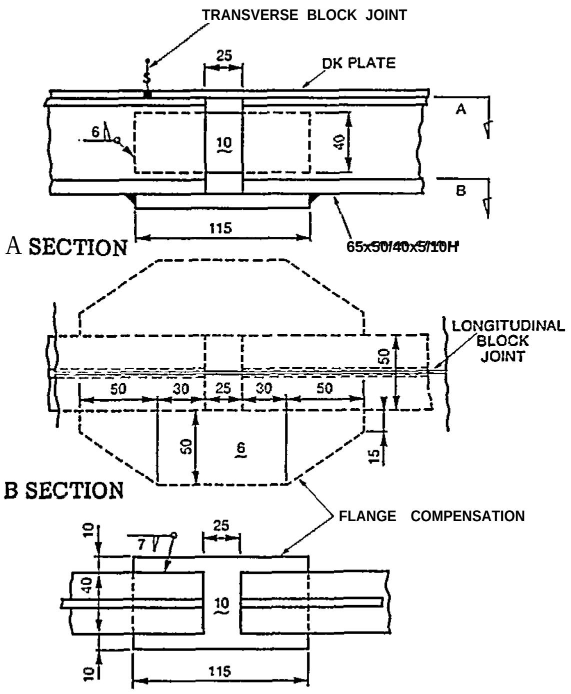


FIGURE 4. “H” BEAM JOINTING METHOD (IN MM)

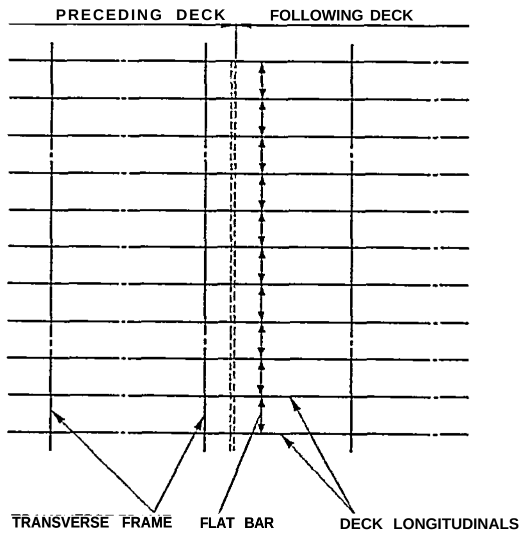


FIGURE 5. TRANSVERSE JOINTING METHOD

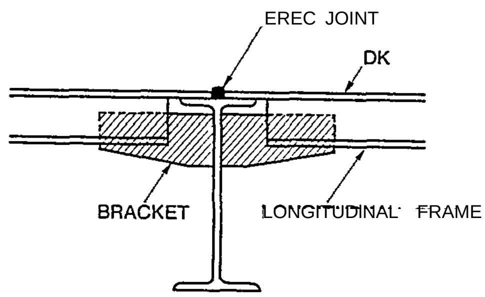


FIGURE 6. METHOD (a) APPLICATION AT TRANSVERSE JOINT

(2) Corrugated plate

Adoption of corrugated plate to compartment partitions provides a big advantage in distortion control because of less heat input compared to flat plate assembly. Corrugated plate was designed to be applied as much as possible where the following conditions are assured.

a) Not to be transverse structural members.
b) Plate thickness is 4.5mm
c) Partition length is 2.lm long or more so that at least 3 ridges can stay on. (ridge space of corrugated plate : 0.7m)

70% of the compartment partitions in the entire ship were satisfactory to the conditions. This resulted in a total of 2000m long, 220tons, of corrugated partitions.

Figure 7 shows the typical profile of a ridge,

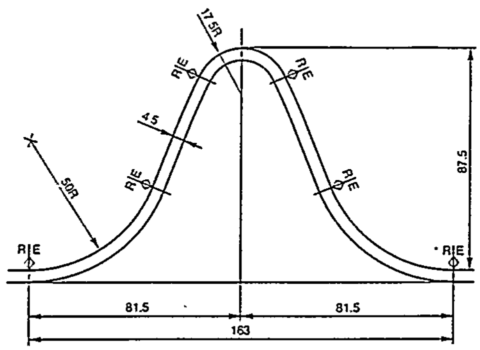


FIGURE 7. RIDGE PROFILE (IN MM)

(3) Panel breakers

Besides restricting welding heat input, installing panel breakers' is also an effective means of controlling distortion on thin steel plate. 'Panel breaking' is an arrangement of breaking panel down to smaller ones by installing flat bars, and thereby gaining stiffness of an entire panel.

Reinforcement of the public space deck was a typical application of panel breakers. Compartments near the engine room, the biggest source of vibration, were also reinforced in order to eliminate resonance by changing the characteristic frequency of each panel.

The application details of flat bars were determined after conducting experiments on model blocks. The following matters were affirmed:

a) Minimization of installation manhours.
b) Line welders are to be applied to longitudinal beams even in the case flat bars are installed before beams.
c) Not disturbing heat insulation work.
d) Obtaining prescribed characteristic frequency.

A flat bar has 3.5mm leg length of continuous-one-side-welding with both ends unwelded, with no snips on the corners. The line welder's paths were secured by installing the flat bars with a distance of 70mm at each end from a longitudinal beam. Since the depth of a flat bar, 32mm, was smaller than the insulation thickness, no swelling up of insulation at a flat bar was necessary. Figure 8 presents the detail of a flat bar installation as a panel breaker.

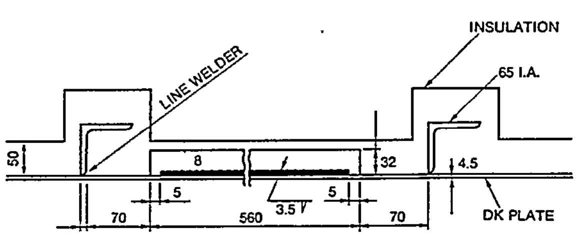


FIGURE 8. FLAT BAR INSTALLATION DETAIL

2. CONSTRUCTION METHODS

(1) Block break down

The types of distortion previously discussed are local distortion, and usually Occur at the sub-assembly and assembly stages. The other type of distortion that occurs at the erection stage, which extends over a wider range than local distortion, needs another approach.

Distortion at the erection stage is considered to be caused mainly by heat of welding at an erection joint. Moreover, the welding method with the least heat input at erection is empirically down hand welding. Three principal ideas of block break down were brought up for review. Talbe 1 lists merits and demerits of each idea.

Figure 9 presents a section view of the block break down that was settled upon. The superstructure consisted of three grand assembled blocks, port, center and starboard, each of which held four decks in it. "F" shaped blocks on both sides characterized the block break down of the ship because it made it possible to apply down hand welding in full scale. The total length of a flat block was limited to 13m maximum for better handling.

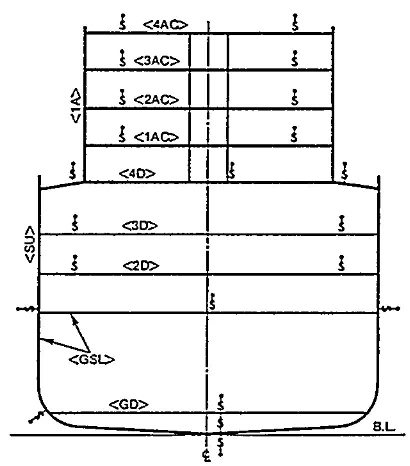


FIGURE 9. BLOCK BREAKDOWN

(2) Welding (beams and stiffeners to plate)

Controlling heat input is a fundamental approach of the welding methodology used for distortion control in the processes of thin steel plate construction.

Short intermittent welding - This was applied to decks #5 and above. Figure 10 shows the sketch. 75mm beads were applied at intervals of 350mm by a modified line-welder which is a semi-automatic CO2 welding machine.

Leg length **control** - In commercial ship construction, leg length of the welding bead, which is an indication of the amount of deposited metal, tends to be 30% to 40% more than that designed. As extra deposit is a formidable cause of distortion, so full application of automatic welding method was investigated and subsequently implemented.

Modification of automatic welder - Methods most commonly applied to small deposit welding with 4mm and less leg length are:

* Small rod gravity welding method.
* CO2 semi-automatic welding method (Line welder).

The CO2 semi-automatic welding method reduces heat input with its higher welding speed, as opposed to the gravity rod.

This time, a modified version of a line welder was developed through trials on model blocks. The modification proved a satisfactory result of the required automatic intermittent welding and sound penetration at both ends of a bead. The specifications of the modified line welder are:

* Welding speed	400 to 1,250mm/min
* Driving motor	DC24V 15W
* Unwelded end	85mm
* Angle sizes applicable	65 to 75mm, 90 to 300mm
* Dimensions	320mmW x 180mmLx 260mmH
* Weight	8kg
* Special functions	intermittent welding, simultaneous weld at both sides

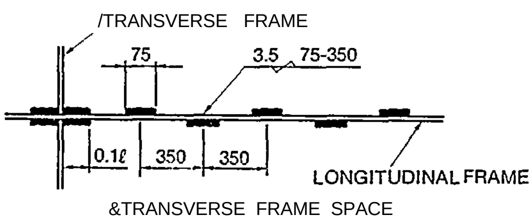
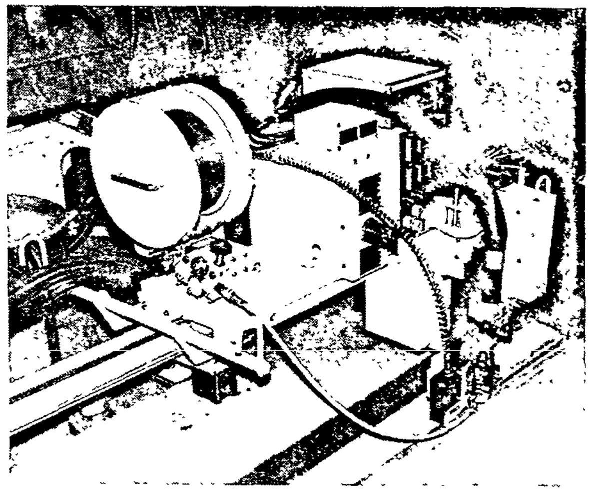


FIGURE 10. SHORT INTERMITTENT WELDING

(3) Plate joining

The plasma arc welding method was applied for the plate joining process of the assemby stage. An automatic plasma welding machine was used, figure 11, which was developed under the three year joint effort with a welding machine manufacturer. Fugure 12 illustrates the drastic reduction of deposited metal. The machine provides the following features.

a) Capable of welding thin plates, mild steel or high-tensile-strength steel, with 2.3mm to 6.0mm thick.
b) Welding control with visual sensing and real time feedback.
c) Applicable to the "I" shaped groove with 0.5mm to 2.0mm gap.
d) The amount of distortion is approximately l/8 of that experienced with the conventional MA-welding method. (figure 13)



TYPYCAL CONDITIONS (THICKNESS : 6MM)

Center gas H_2 7%, Ar93% (ℓ/min)	Shielding gas Ar100% (ℓ/min)	Welding current			Wire feeding speed (cm/min)	Welding speed (cm/min)
		Base (A)	Peak (A)	Frequency (Hz)		
2.2 ~ 2.4	15	120	280	500	140 ~ 160	25 ~ 30

FIGURE 11. AUTOMATIC PLASMA WELDER

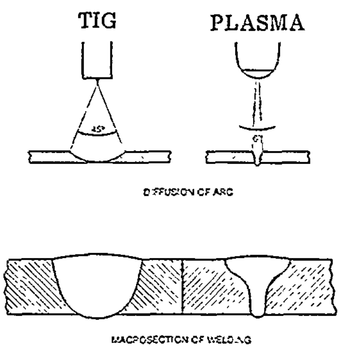


FIGURE 12. PLASMA AND TIG

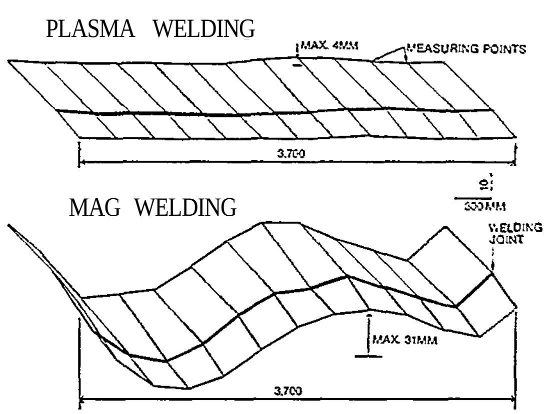


FIGURE 13. DISTORTION COMPARISON (6MM THICK PLATE WITH I-GROOVE JOINT)

Table 1. Block break down methods

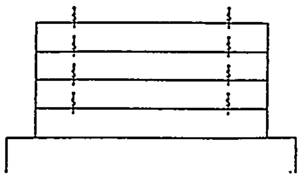
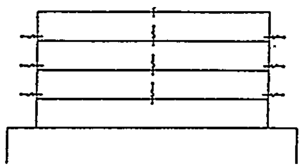
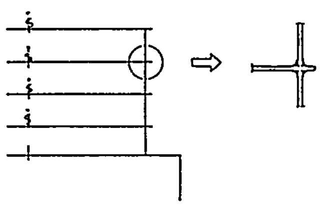
Type	Configuration	Merit and Demerit
F		(Merit) Provides down hand welding. (Demerit) Increases onboard connections of pipes running P-S.
L		(Merit) Decreases onboard connections of pipes running P-S. emerit) Increases horizontal welding length and total erection welding length.
U (L)		(Merit) Provides down hand fillet welding. (Demerit) Worsens smooth appearance of outside wall.

Table 2. Outfitting guide lines

1. Pipe support installation onto skin plate.
   1) Avoid direct installation onto skin plate without beams or flat bars on the other side.
   2) Exceptional cases;
      * On deck plate where deck composition covers later.
      * On compartment partitions.
2. Doubler plate fitting.
   Fit doubling plate at every foot of support that is installed onto skin plate.
3. Deck or bulkhead penetrations.
   Apply sleeve type penetrations rather than flange type as far as possible.
4. Welding.
   Apply welding rods of 2.6mmø or 3.2mmø unless otherwise specified.
   Maintain leg length of 3.5mm or less.

(4) Outfitting

A model block was also dedicated to conducting tests to establish guide lines of outfitting work on thin steel plate. Plate distortion was measured through processes of burning and welding penetrations as well as installation of the other fittings directly attached to the plate surface.

Burning - Roth propane-gas burning and plasma burning were tested. Plasma burning showed its advantage, specially in the case of burning several holes adjacent to each other. Plasma burning was subsequently adopted to the ship.

Closing holes - A comparison between overlapping (with fillet welding) and inserting (with butt welding) was made. Inserting was proved to be advantageous due to its less welding length.

Pipe support installation - 3mm maximum distortion was found due to welding around pipe support (50mm x 50mm angle steel) to plate surface. No significant redution of distortion was seen by inserting a doubler at foot of a pipe support.

Examples of established outfitting guide lines are presented in table 2.

VERIFICATION

Each method under consideration for application to the ship construction was first verified experimentally on model blocks in order to make sure it worked.

Throughout the hull construction processes, distortion on every hull block was measured and statistically analyzed for the evaluation of methods and for further improvement.

Immediately after the completion of hull structure and engine room outfitting, the ship cruised, under self propulsion, 300 nautical miles on the sea on its way to the pier where it was planned that the joiner work would be completed. This is called “the steel trial.” The task force took the full advantage of this opportunity by measuring vibrations on uncovered bulkheads and decks.

CONCLUSIONS

Although, at the submittal of this paper, the ship is not yet delivered, it can be said that the task was very successful.

Fairing manhours per square meter in the ship were 37% less than that obtained in a ferry boat constructed in 1989. This is quite satisfactory because the ferry boat had similar principal dimensions as the passenger ship, and had a superstructure constructed mainly of 6mm and 7mm thick plate. The improved fairing manhours per square meter has greatly encouraged releasing compartments to painting and outfitting just-in-time. This has been of course the greatest contribution to achieving quality satisfaction, schedule adherence and cost reduction.

The vibration measuring during the steel trial resulted only in a few additional local reinforcements onto the structure.

The most remarkable items that will contribute to suppressing plate distortion are summarized:

1) 3.0mm to 3.5mm of fillet leg length was successfully obtained.
2) An "H" beam right underneath a joint was proved to be effective.
3) Plasma arc welding is, at present, the most effective welding method for joining plates with 6mm and less.

We have been successful in obtaining valuable outcomes for thin steel plate construction practices. However, it is also true that we were not able to resolve the big questions that came up among the task force members, “why does it have to be 4.5mm?,” "why can’t 5.0mm with less beams or flat bars be an alternative?” The next challenge is to seek the ideal combination of plate thickness, longitudinal beam space, transverse beam space, and block breakdown.

ACKNOWLEDGEMENTS

The author wishes to express appreciation to T. Tanaka, the task force leader, and his task force memebers for the excellent contribution to this paper.

Special thanks are also due to colleagues in IHI M. Maeda, H. Endo, T. Saito and S. Sato for their constructive criticism and advice.

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Paper presented at the NSRP 1990 Ship Production Symposium,
Plister Hotel, Milwaukee, Wisconsin, August 21-24, 1990

SEAWOLF Producibility II: Transition From Design to Production

7A-2

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ABSTRACT

SEAWOLF Producibility initiatives have been presented to past Ship Production Symposiums. The technical content of these papers was based on work accomplished during the SEAWOLF Detail Design effort and articulated the point of view that the SEAWOLF Producibility Program was an important step in advanced ship production. The lead shiv of the SEAWOLF Class started construction in late 1989. The opportunity now exists to validate a number of the elements of the design for production. Electric Boat Division, as Lead Shipbuilder, has the opportunity to review a number of the specific initiatives, such as Digital Data Transfer, Sectional Construction Drawings, Planning and Sequence Documents, Computer Integration of information processing and the combination of SEAWOLF products that support improved work control. The method of approach is to describe the SEAWOLF producibilitv element developed during detail -design and then assess the benefit to the shipbuilding process.

INTRODUCTION

The SEAWOLF Program has reached a pivotal point in its history. During the last 10 months, the Detail Design and Lead Ship Construction have become coincident, as Detail Design continues and lead ship construction gets underway. The Program has entered perhaps its most active phase, and in essence, the software products of the design effort are being converted into hardware at the Electric Boat Shipyard in Groton, Connecticut.

The design products now being utilized in Groton are different than for previous submarine designs. The difference is due to advanced technology being infused into the submarine design and construction effort, and developed into design deliverables through what has become known as the SFAWOLF Producibility program. Although the final quantitative results of the Producibility effort are still to be determined, several of the features have developed to the point where their benefit can be evaluated.

The products of two broad efforts, the Digital Data Transfer Program and the SEAWOLF Advanced Planning Program, have been extensively utilized during the pre-construction and early construction phases of the lead ship contract. The design deliverables from these two programs that are provided to the Shipyard are based on procedures and agreements that are embedded in the SEAWOLF Ship Specification and Detail Design contracts. The impact of these deliverables on the construction activity can now be evaluated with an environment in which ships are being built using conventional design products.

SEAWOLF PRODUCIBILITY

The SEAWOLF Producibility program originated from the goal of greater affordability in ship construction. Shipyard modernization programs at Newport News Shipbuilding and Electric Boat Division provided the opportunity to change the philosophy and products of submarine design. The Producibility Program was initiated with construction as the primary focus; however, it has become increasingly apparent the post delivery phase of the ship's life cycle will realize significant benefit. In fact, the logistics community has already begun the effort to utilize the digital information available from the design to initialize the logistics data base.

The SEAWOLF Producibility effort was inaugurated primarily because computer technology and zone logic based construction had reached sufficient maturity in the submarine

shipyards to facilitate a change in design philosophy. Although the principle of designing for production was nothing new, the SEAWOLF Program extended the logic beyond previous experience in naval ship production. A number of self evident assumptions underlie the producibility effort. Those particularly important to this paper are:

- Create data once and use it many times;
- Electronically transferred data is superior to paper products:
- Close inter-relation of the design product to the construction plan will yield greater control over both processes; and
- An electronic schedule management too1 has the capability to simplify the immensely complex task of building a ship

These assumptions could be supported as intrinsically valid, but could they be developed by the SEAWOLF Program into design products that fully supported construction?

Design

The SEAWOLF ship specification required the design to be computer based, electronically transferrable to the two potential shipbuilders and to utilize a product work breakdown structure that supported submarine zone (modular) construction.

In early 1987, the program moved from a contract design competition between Electric Boat and Newport News into dual design yard responsibility for detail design. Part of the transition process was to create the organizations that would formalize the embodiment of the goals into well defined design products. The goal of transferring digital products from design yard to construction yard was the task of the SEAWOLF Digital Data Transfer Working Groups. The process of structuring the design to support modular construction was assigned to the SEAWOLF Producibility Steering Group.

Transition to Construction

The flow of information from design to construction will be explored by reviewing the effort that created the design product in question, noting the present design status, if appropriate, and then looking at the state of implementation in the construction process. The producibility process that developed the form of the design deliverables has been previously documented. For clarity, however, portions of those presentations will be re-presented. The information concerning the design status and construction development has been gathered at the Electric Boat facilities in Groton and Quonset Point, Rhode Island from whom the authors determined to be the most knowledgeable management personnel available. The construction managers were asked to compare the SEAWOLF product with the parallel SSN688 or TRIDENT class design deliverable and comment on the change to their particular job.

DIGITAL DATA TRANSFER

The first area of interest is the Digital Data Transfer process. A similar capability had been developed at both design yards to conduct transfers of various types of data to the shipbuilders. For lead ship construction at Electric Boat there are several additional steps in the process for data received from Newport News for lead ship construction, such as processing the data through the IGES Translator. However, in most cases, the origin of the product delivered to the ultimate user in the construction yard is invisible.

DRAWINGS

The ability to exchange drawings among the design and construction yards was an early goal of the program, which received a large share of the attention and developmental resources. The initial assessment was that an electronic exchange of drawings would provide the construction yard, and later the planning yard and maintenance activities, with a complete, controllable and computer usable set of electronic drawings. The thrust was to make the exchange virtually "perfect" with each graphic detail passing through the translation process in the exact form in which it was created in the originating design yard.

Design

The Initial Graphics Exchange Specification (IGES) was chosen for data exchange since it was a universally recognized standard and

avoided the restrictions of a direct translator. However, the IGES standard, while a powerful guideline for which most Computer Aided Design (CAD) vendors have written translators, is primarily focused on graphic details and does not deal in a straight forward process with the sophisticated embedded intelligence capable of being produced by many CAD systems. Therefore, much work had to be done to modify, or "flavor," the translators to allow clean exchange of drawings between Newport News and Electric Boat. Even now, with considerably enriched translators in place, developed in cooperation with the CAD vendors, a few restrictions must be placed on the CAD user. These restrictions reduce, to some extent, the entire range of features available to the designer in order to accommodate drawing transfer. Nevertheless, providing the drawings are constructed in accordance with the SEAWOLF Program developed procedures, it is possible to consistently exchange nearly perfect drawing files between shipyards.

Drawing Exchange

This process has been used to a limited extent during SEAWOLF design and the early phase of construction. Actual exchange is by specific request, with the requestor paying for the preparation, processing and material cost. Therefore, the requestor selects to receive only the drawings for which modifications at the receiving site will be made. It is anticipated that drawings will be electronically exchanged between Design and Construction agents to complete Selected Record Drawings, as-built drawings and other shipbuilder responsible drawings. Although the exchange of drawings between design yard and shipbuilder is presently limited. it is anticipated that a major exchange of electronic drawing data will occur to position the drawings for SEAWOLF life-cycle maintenance.

To verify the SEAWOLF procedure and attempt to extend the drawings transfer to additional CAD systems, a small data transfer effort was undertaken by Electric Boat, Newport News and General Electric (Information Technology Group, Syracuse, New York). A working group was established to IGES transfer drawings utilizing SEAWOLF documentation. The effort lasted about six months and was highly successful in transferring a variety of SEAWOLF drawings.

PROCESSABLE DATA

Processable data is data element based text information that is used in design and construction in a variety of manners and locations. Therefore, it is data which is most valuable in electronic database format, positioned so that it can be accessed, manipulated and used for multiple applications. Since the SEAWOLF is being designed by two design yards, an important goal has been to achieve electronic exchange of this type of data so that the data can be assembled in one location, the construction site, in the most efficient and effective form.

Design

Since the target data in this instance is textual, an early goal of the SEAWOLF data exchange program was to create a data dictionary, defining the content and configuration of each data element which was a potential exchange candidate. The next step was to group data elements such as part number, material type, etc. into logical sets for exchange. These lists, such as part number catalog and the engineering parts list, became the targets for development of exchange procedures. A variety of processable data exchange categories have been developed and are supported by the SEAWOLF Data Element Dictionary. Principal data transfer reports are listed in Figure 1.

Clearly, the most important target for data exchange is material information, represented by the Part Number Catalog

1. ENGINEERING PARTS LIST
2. PART NUMBER CATALOG
3. JOINT/SURFACE INDEX
4. MATERIAL QUALITY ASSURANCE LIST
5. STOWAGE LOCATION LIST
6. SHIP'S DRAWING SCHEDULE
7. HIGH IMPACT SHOCK DATA
8. PROCUREMENT SUMMARY INDEX
9. WEIGHT AND MOMENT DATA
10. RADIOGRAPHIC SHOOTING SKETCH LIST

FIGURE 1. PRINCIPAL DATA TRANSFER REPORTS

(PNC) and the Engineering Parts List (EPL). Early emphasis was placed on this exchange and has resulted in a working system which consistently provides material information from Newport News which is loaded directly into and merged with the Electric Boat data. A similar process is accomplished at Newport News with Electric Boat data.

Other areas of planned data exchange are going into production at this time. The first tapes of non-destructive test data, containing joint indices and material quality assurance lists, for example, will be exchanged shortly. Procurement summary indices, provided by the shipbuilder and containing information on material order by Electric Boat scheduling and status, have been made available electronically to Newport News. Most of the other data relates to logistics and life cycle maintenance and is not immediately required for construction. Plans for these exchanges are being completed and the data will move among the established logistics systems, such as the lead design yard developed SEAWOLF advanced integrated logistics support system (SAILSS).

Processable Data Exchange

The concept of electronic exchange of data, particularly with respect to material data, has been well received by both the design and construction yards. They have established good working relationships, and an excellent approach through the development of a common data dictionary, since it is recognized by all parties that success would be a win-win accomplishment.

According to the shipbuilder, recognizing that the EPL is essentially the complete definition of the ship without the graphics, early identification is important. Electronic exchange provides this insight, particularly if material data captured early in the design process and made available. The ability of the design agent to concentrate on the capture of material description data and early availability of this data, even if preliminary, is an essential feature of a systematic lead ship construction process.

In addition to earlier visibility, the electronic exchange of data has afforded other advantages. It has eliminated tedious manual loading of thousands of lines of information, with the attendant labor saving and reduction of errors. Also, it maintains the responsibility for accuracy with the data originator, rather than transferring that responsibility to the user upon when manually loaded into his systems. This reduces data verification by the user to an overall system check and allows problem correction at the source, as it should be.

One area that requires additional procedural development in the processable data is the need to relate various types of data (drawing schedule to material to joint list to material qualification, etc.). Presently, separate tapes, each containing one type of information, are exchanged on a regular (monthly) basis. While eventuallv all the data can be tracked and linked, several exchange cycles may be necessary before all of the data required to support, say, a particular drawing is available. A potential improved system would establish and agree upon a base "root" such as the drawing schedule, and time the release of all related data to the root release.

MODEL DATA

The initial emphasis in the SEAWOLF data exchange program was placed on drawings and processable text. Model exchange (Three Dimensional (3D) CAD representation of geometry) was considered potentially valuable, but the perception was that this exchange would be more technically demanding. The model exchange effort was initiated by evaluating the different design and construction disciplines from the standpoint of utility in the manufacturing process. The decision was made to focus the initial effort on structural and piping models, since considerable numerical control manufacturing capability was resident in both Shipyards. It was believed that success in these two areas would be more advantageous than partial success in all disciplines.

Design

Although much time was spent determining the format, content and procedures for model transfer, the technical issues proved to be less demanding than for the drawing transfer process. This is because the aim of model transfer was to exchange geometry, rather than the subtleties of text and embedded intelligence. Geometry is what IGES was developed to handle, and once agreement was reached on what to exchange, the "how" was

relatively straightforward. This was particularly true for structure, for which it was agreed to exchange wire frame geometry, grouped to define individual piece parts, with only piece identification numbers being overlaid as added intelligence. A 2D representation of a wire frame model is shown in Figure 2. The development of procedures to exchange piping was somewhat more difficult in that both shipyards were using piping design systems developed in-house, and therefore each yard had to develop its own IGES translator. In addition, piping data transfer is more complex due to the need to include complex detail such as fitting valve and joint design data. In fact, this effort has been so successful that the methodology has been drafted into a formal procedure (protocol) and submitted to the committee that oversees improvements to IGES for inclusion in the specification.

The status of the production exchange of model data is that procedures for structure and piping data are complete and tested. Structural data has been flowing through the system since late 1989, and the initial packages of piping data are beginning to appear. The model exchange, by agreement, is done by transferring the appropriate data contained within a structural or piping SCD, essentially in parallel with the issue of the hard copy drawing.

The process in place for transmittal of structural models to the construction agent, and their subsequent uses: For design work being done at Electric Boat, the issue of an SCD triggers an action in the Engineering Data Support group to collect the models from which the SCD was created, activate specially designed software that generates a single model, stores the model in the manufacturing database, and informs Construction Planning of the completed action. For design work being done at Newport News, both the model geometry tapes and hard copy drawings are received by the SEAWOLF Engineering Configuration Management group at Electric Boat. The drawings are processed for distribution, and the model tapes are forwarded to Engineering Data Support. This group processes the model through the IGES translator, stores it in the manufacturing data base and informs construction planning of its availability.

For piping, the process is generally similar except incoming data from Newport News is translated into input for the Electric Boat piping design/manufacturing system. After being run through this system the output in the form of both graphic detail sheets and NC data is stored in the manufacturing data base from which it is retrieved on schedule demand by the planning group for work package preparation and by manufacturing for numerically controlled pipe detail bending.

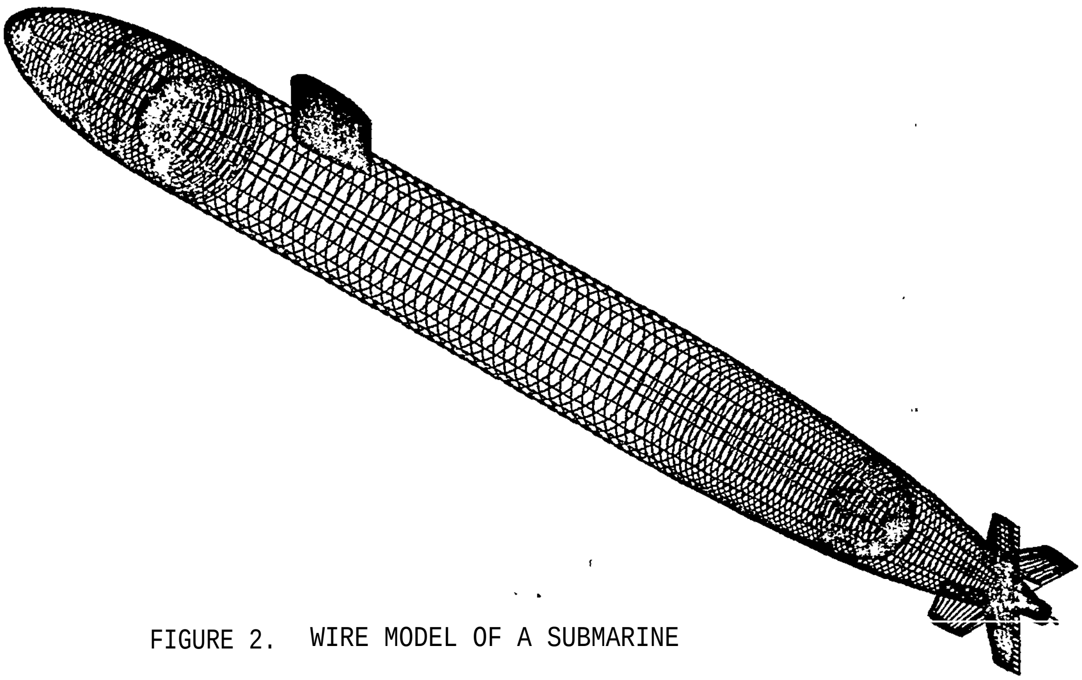

FIGURE 2. WIRE MODEL OF A SUBMARINE

Model Data Exchange

As a result of the data exchange processes developed for SEAWOLF, the methodology for preparing steel parts for cutting, the traditional "lofting" function is changing significantly.

With previous designs the traditional design deliverable was a paper drawing of an assembled structural component, piece-marked and dimensioned to define individual piece parts. The loftsman deduced the shape of each part from the assembled views shown and the explicit and implicit dimensional data. From other information provided, such as weld requirements, orientation, thickness, and shipyard construction experience and preferences, he determined the additional manufacturing details such as kerf, bevel, expansion and extra stock. When all of this data was accumulated he wrote the "program" which created an electronic description of the geometry and ultimately drove the numerically controlled burning equipment that cut the pieces.

For SEAWOLF construction, the data provided to the construction agent is of two forms: an SCD with a chapter showing and dimensioning the true design shape of each steel piece as well as chapters showing assembled and installed views and dimensions, and a full scale electronic wire model of the structure with each piece identified as a separate 3D entity.

The availability of this data changes the process for part preparation.- Now a part planner/analvst studies the individual part geometry as well as its context in the assembly and installation shown in the various SCD chapters. He then simply annotates the part drawing with the required manufacturing details and passes it to a part programmer. The part programmer, skilled in manipulating geometry on a CAD system, calls up the design geometry of the individual part from the electronic model provided and adds the manufacturing details. At that point, the numerical control programs are automatically generated for eventual incorporation into a plate nest of many parts for cutting. A series of computer graphic plots of this process are shown in Figure 3.

This new process, currently being employed in SEAWOLF construction at Electric Boat, results in several significant improvements over the traditional methods. First, the availability of individual part as well as assembly data in the drawing, along with the actual electronic model, allows a division of labor in part preparation which was not practical before. The analyst must be an individual with substantial construction and construction planning experience, but he need not be skilled in part programming, since the part geometry is already defined and electronically available. Similarly, the part programmer need not possess the skills of analyst, since he is only required to modify the existing geometry based on the analyst's direction.

The division of skill mix allows more flexibility and ease of staffing. Worker's skills and job assignment are more easily matched-and optimized to maximum efficiency. Design geometry need not be recreated, or even checked, since it is provided in the same model form from which the drawing was created. This reduces transcription and interpretation errors.

This last point highlights an even more important difference than part preparation labor saving. With the old method, the loftsman had to re-create the geometry developed by the designer in order to provide data for part cutting. In essence, this transferred responsibility for geometric accuracy from the designer to the builder. For SEAWOLF, with part geometry being provided electronically by the designer, responsibility for geometry remains with the design agent. This important cultural change must be equally realized by both designer and builder. The designer must be sensitive to producing 100% accurate geometry, not just a picture with reasonable likeness. The builder must resist making geometric changes that could alter the design intent. Instead, he is obligated to feed geometric change data back to the designer for model correction.

At Electric Boat, these processes have been employed since the start of SEAWOLF Construction in October 1989. At the time of this writing only a small percentage of the total steel parts have been processed, many of which are large structural hull pieces. Therefore, definitive process improvement and cost saving parameters cannot yet be quantified. However, certain trends are beginning to emerge.

The Steel Process Group reports that less time is now required to process parts than with traditional methods, although this saving is more evident with complex parts than with

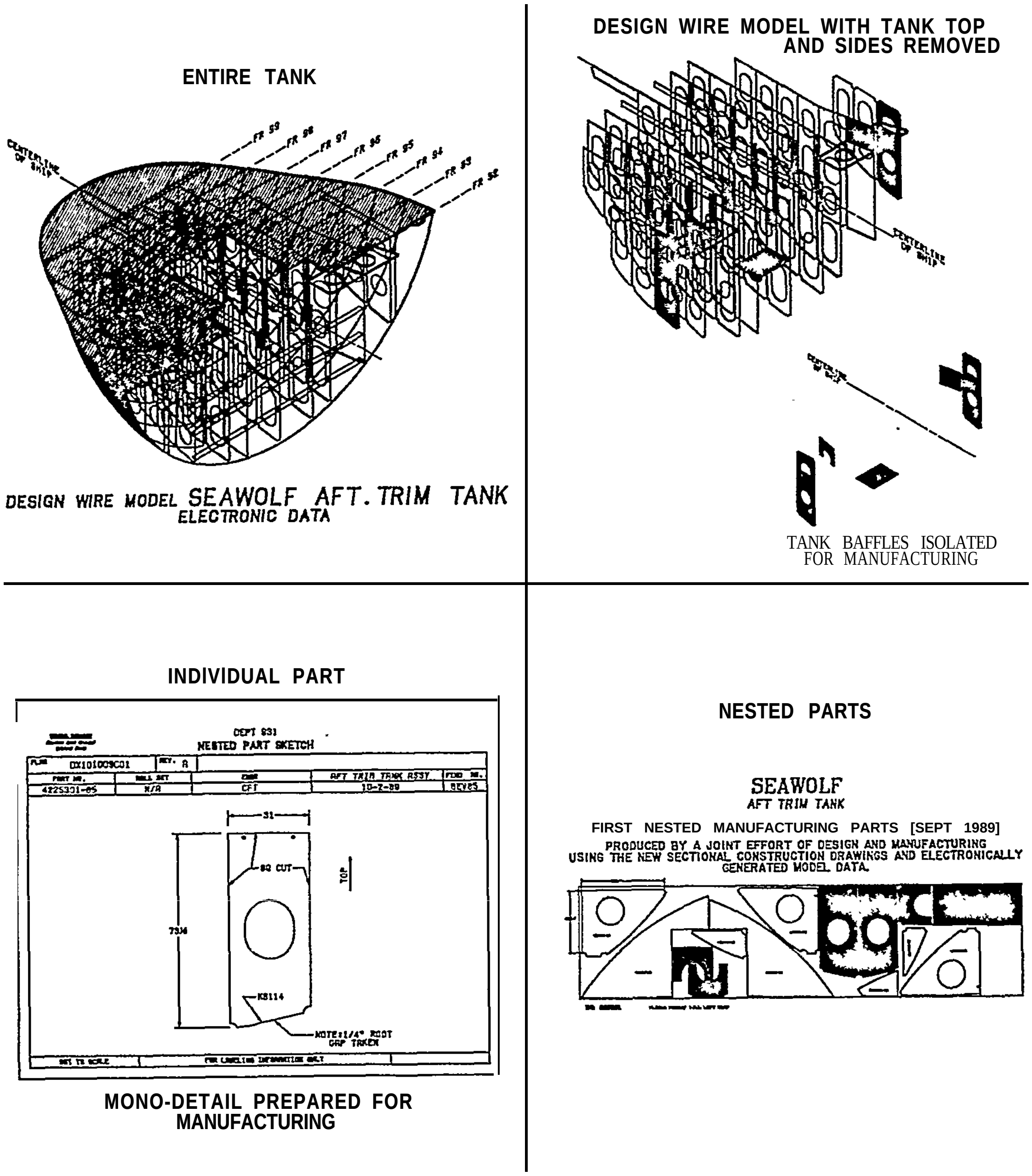

FIGURE 3. GRAPHIC PLOTS OF THE COMPUTER LOFTING AND NESTING

simple shapes. Also, they have been able to staff up more easily due to the skill separation noted above. The group reports that it is not necessary to validate design geometry: and they rely totally on what is provided in the electronic model. Evaluation to date does not indicate any problems in manufacture or assembly due to geometric errors in the models. An additional advantage is the ability to use the model geometry and available CAD software to expand shaped parts to flat cutting patterns without manual lofting, and the ability to create roll templates directly from the electronic model. Other advantages noted are the ability to easily produce electronically generated sketches of parts annotated with manufacturing data such as bevel and root gap. These are provided to the assembly trades as supplements to the assembly views of the SCD's, promoting better visualization of the fit-up and welding requirements. To quote one steel processing supervisor: "The difference in methodology is like night and day. We still don't know all of the advantages to be realized as a result of the availability of the electronic model".

FUTURE DATA EXCHANGE ACTIVITIES

The initial data exchange activities have matured to success over the last three years. It has become apparent to both Design and Construction management that value could be added to the SEAWOLF Program by expanding data transfer into other disciplines. A study of future data exchange possibilities was conducted. The areas of overall greatest potential were Heating, Ventilation and Air Conditioning (HVAC) Ductwork and Electrical Wireways, due to existing facilities that would immediately benefit from the receipt of digital data. Both of these areas could be approached in a two phase development that permitted early results followed by a more complete and richer procedure.

For HVAC, both shipyards have agreed to use the same procedures to develop most of the ductwork from a series of standard parametric shapes. Using these shapes, software automatically generates the flat patterns for manufacture. Therefore, to achieve immediate aid in manufacturing, the first phase will be to exchange the size parameters of the standard shapes, which can be processed by the manufacturer directly. In the follow-on phase, the approach will be expanded to exchange complete model geometry from which the recipient can extract the parameters as needed for manufacture. This procedure will be particularly useful for any sheet metal structure, especially those composed of non-standard shapes.

For electrical wireways, the primary data requirement is associated with cable routing. That is, the routing of each cable through the individual wireway hangers of the ship. The transfer of the cable routing information, essentially textual data in a tabular format, would be the first phase of effort. The second phase will expand the procedure to include 3D model data of the wireway and associated hangers.

A third new data exchange medium recently began in the area of critical path network scheduling data. Both shipyards and the Navy are using the same network scheduling system. A logical extension of data exchange was to transfer each other's data so that all parties had complete planning networks available in native format to provide the user maximum utility of the software. The primary focus of the procedure development was to coordinate data element similarity and ensure network detailing was compatible. The completion of this effort has facilitated the future transfer of scheduling data from design yard to shipbuilder, extending the SEAWOLF philosophy of maximizing construction planning in the design phase.

CONSTRUCTION PLANNING

The second producibility initiative explored is that of construction planning. The traditional task of the various planning groups was to assemble design information, primarily drawings, and create the work packages, schedules and other information required by the trades to construct the ship. The tools of the shipyard planner have changed from a number of separate bodies of data that were entirely paper based to computer data bases that have the capability to be interrelated.

The design deliverables to the construction yard are dramatically different than those received from previous submarine efforts. The conventional "class" system based drawing has been replaced by the zone based Sectional Construction Drawing (SCD). In addition, detailed schedules are provided in the form of planning and sequence documents. As related earlier in the digital data transfer section, construction planning has been approached in a similar manner. A description of the design products is re-presented below from previous efforts and the utility of the new product is recounted from discussions with construction management personnel.

SEAWOLF Drawings

A special effort of the SEAWOLF Producibility initiative was the redefinition of the types, formats and levels of detail of SEAWOLF drawings. This redefinition was required to fulfill the goals of improving the utility of construction drawings, supporting zone construction and reflecting the results of the planning effort conducted during detail design. The SEAWOLF ship specification defines three types of construction drawings to be created during the design process:

1. Configuration:
2. Sectional Construction; and
3. Ship Support.

Configuration drawings are system oriented drawings that are required to create the design data base. Most configuration drawings require approval from government agencies such as NAVSEA or the cognizant Supervisor of Shipbuilding. The format of the configuration drawings has changed little from the "class" drawings that are common to previous ship designs. The level of detail is reduced in some drawings, since any detail not required for approval, but was previously added only for construction, does not appear on the configuration drawing. SCD's are a translation of the same data base used to develop the configuration drawings, reconfigured to support zone oriented construction. The intent of the SCD is to provide the shipbuilder with all the information needed to construct the ship in the most useful format possible. A detailed review of the SCD and its role in SEAWOLF construction is provided later. Ship support drawings will be used in the life cycle support of the SEAWOLF and are composed of configuration and SCD's; and an additional group of drawings created for life cycle support such as docking drawings, equipment removal flow path drawings and Selected Record Drawings.

Sectional Construction Drawings

The SEAWOLF ship specification defined the purpose of an SCD, but it was left to the Producibility Steering Group to structure this new type of drawing. The goals in creating the SCD were:

1. Support zone oriented construction:

2. Create logical work packages;

3. Insure the drawing could stand alone in the work place; and

4. Reduce additional planning by the shipbuilder.

Supporting the construction scheme through the SCD's was accomplished by equating each drawing to an interim product, whether that product is a small item or a large module. The SCD starts with the definition of the interim product and then works through the material and processes that create that product. In the case of an item level product, such as a foundation or a package of pipe, the SCD starts with a raw material parts list, consumes the material in manufacturing processes, prepares the item for joining with other products and may install the item on the next higher level if appropriate. A module SCD would start with previously assembled interim products, such as items, and sub-modules and then work through the required sequence to assemble the module. An illustration of the work breakdown structure and interim products is shown in Figure 4.

In order to identify the interim products and provide an easy to use linkage for the SCD work elements, a system to "intelligently" number the SCD's was created. Since constructing an interim product is in most instances a multi-step endeavor, the creation of an interim product can be divided into steps that logically define the process. Figure 5 shows the chapter expansion of an SCD that fabricates and assembles a package of pipe. The numbering of the chapters is uniform: for example chapter 04 always assembles structural piece parts and chapter 34 always assembles piping piece parts.

The SCD Chapter is structured so that it can stand alone as a work package with minimal additional documentation. If any design reference provides information actually required for manufacture, then the information from that reference is included in the SCD. The chapter can also stand alone from the overall drawing, in that it can be detached from the SCD and sent to the work center that requires the information.

The complexity of nuclear submarines has increased dramatically over the years and SEAWOLF will continue that trend. The SCD provides the shipbuilder a tool to handle the complexity by presenting detailed yet simplified views of what is to be built, without extraneous information. The SCD presents the construction planner with the logical work packages that reduce the need for detailed advanced planning. The work breakdown or "granularity" of the work units has been refined to the point that resource accountability can become a reality. The completion by a shop of a drawing chapter indicates that a product has been built, or a specific value added, such as sandblast and paint of a unit. The shortened work timeframe and improvement in the ability to equate work package scope to physical progress brings a better tool to the construction process. The SCD achieves the goals that are detailed in the ship specification and is a measurable achievement in advanced ship production.

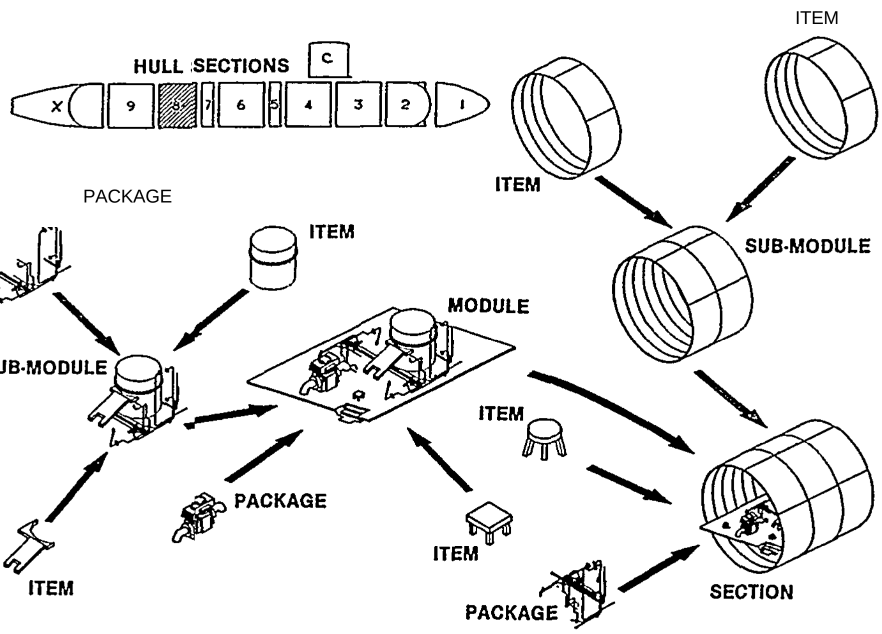

FIGURE 4. SEAWOLF PRODUCT STRUCTURE

Planning and Sequence Documents

The process of creating interim products from the item level up to the section level evolves a logical sequence of assembly above the SCD Level. As the design is iterated and the design spiral tightens, the assembly sequence becomes a parameter affecting design decisions. To assist designers in understanding the construction process, knowledgeable construction planners have been brought into the SEAWOLF detail design effort. One of their tasks is to arrange the fabrication and assembly of interim products into a scheme that fits into the facilities and practice of submarine shipbuilders. The planning group utilizes a computer based critical path software to lay out the logic of SEAWOLF assembly. All the SCD's necessary to produce an interim product at the module or section level are networked together to permit review and analysis of the proposed construction sequence. These networks are titled "sequence" documents and are the foundation for creating additional schedule related

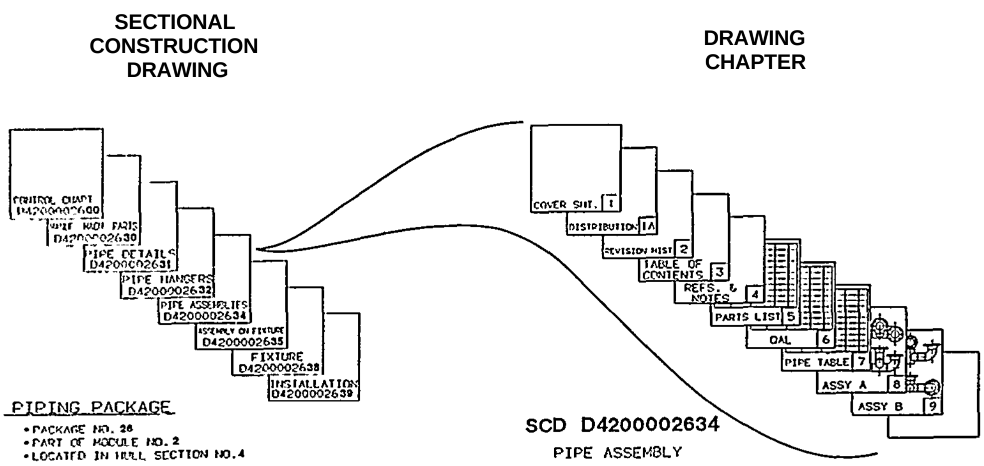

FIGURE 5. SECTIONAL CONSTRUCTION DRAWING CHAPTERS

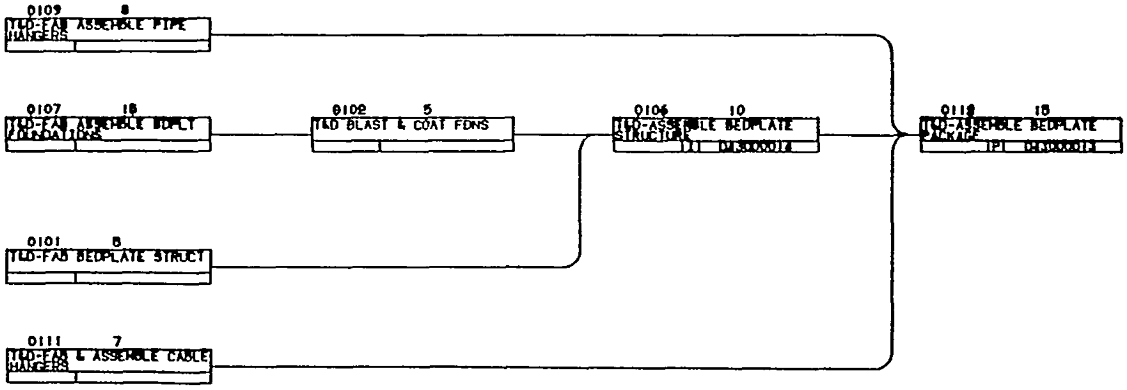

FIGURE 6. SEAWOLF SEQUENCE DOCUMENT

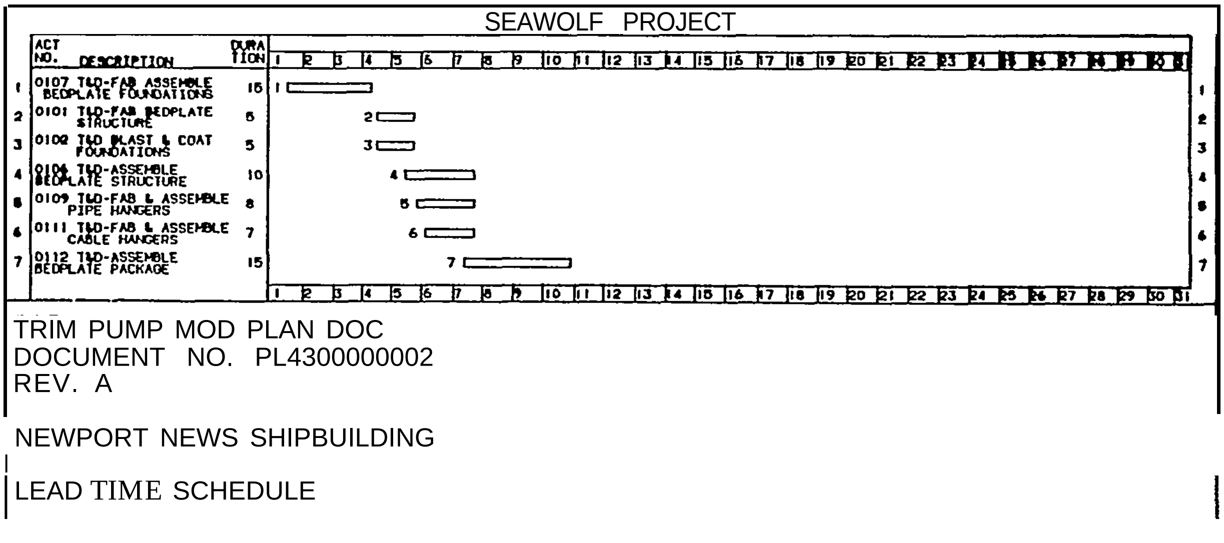

FIGURE 7. SEAWOLF PLANNING DOCUMENT

products. An example of a small portion of a sequence document is illustrated in Figure 6. The first derivative product is created by the addition of an estimated time frame to each event of the sequence network, yielding the "planning" document. The utility of the planning document is the ability to capture information necessary to work out a finite construction period and allow critical path analysis of the nominal construction plan. The companion planning document to the sequence document in Figure 6 is depicted in Figure 7. Condensation of each planning/sequence network into a single event becomes the basis of the Master Construction Schedule (MCS).

Figure 8 illustrates the evolution of an MCS activity from the planning and sequence documents. Since the MCS is produced from a "bottom-up" approach, based on a product by product evaluation, it is a valid scheduling tool that is available at the outset of construction. From the MCS, other data bases, such as the drawing issue and material ordering schedules, are linked in order to achieve an integrated construction plan. The products needed by the shipbuilder, in accordance with the Master Construction Schedule become the driving force in meeting design issue schedules that support lead ship construction.

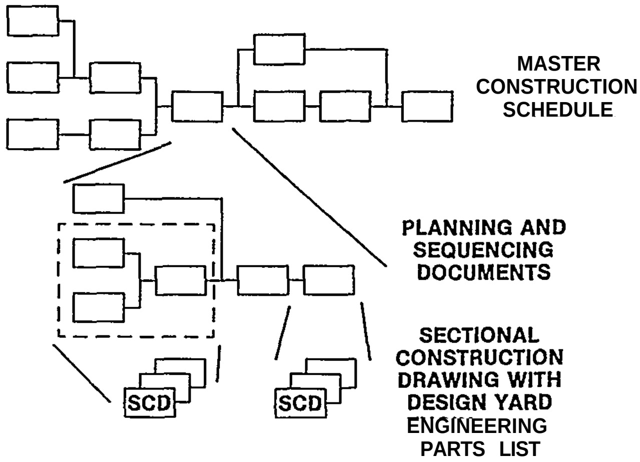

FIGURE 8. RELATIONSHIP OF SECTIONAL CONSTRUCTION DRAWING TO PLANNING AND SEQUENCE DOCUMENTS TO MASTER CONSTRUCTION SCHEDULE

SHIPBUILDER PLANNING

The inclusion of product structure planning in the SEAWOLF design contracts, the availability of the SCD's and the use of computerized network planning tools are generating significant impact in the preparations for construction, according to Electric Boat planners.

The SEAWOLF design contract requires that planning for construction be integral with detail design and that the SCD's be configured to follow the construction sequence. Electric Boat planners say that this results in the evaluation of the construction sequence "two or three times" before final preparation of the deliverable drawings and sequence documents. This, in turn, provides a running start in the planning of shipyard specific work packages, providing more insight, at an earlier point in time, into the total ship construction requirements. Furthermore, the finer detail in the product structure provided by the design agents allows more accurate, detailed and timely forecasting than has ever been possible before.

This comprehensive and detailed pre-planning paves the way for development of shipyard work packages and schedules with far shorter work scope time spans and more specific requirements than was possible with conventionally prepared design documentation. This in turn is leading to better, earlier visibility of material and manpower requirements, more precise tracking of progress, and better problem feedback, with more rapidly applied corrective action. The Electric Boat planners are convinced that there will be no more "three year, 43000 hour work authorizations for which we are expected to track progress, monitor cost, and react to problems and changes. With a two-week work scope, you can monitor and identify potential problems and react before they can blow up."

While it is acknowledged that not all operations may require SCD's (such as for valves, liners, standard and small parts, etc.), they are valued as the primary "building blocks" for development of construction work packages. In particular, the construction planners stress the expected value of higher level SCD's which define assembly and installation requirements for large modules. They see these as providing invaluable information and graphic aids to the assembly trades. So valuable are the SCD's perceived to be, that the construction planners have said they would "go crazy" if forced to revert to conventional drawings.

Product structuring and the of computerized networking tools have made the construction planner's job easier. Furthermore, they facilitate more precise and timely status reporting to management. The real world of shipbuilding will undoubtedly cause the planning group to accommodate a variety of problem scenarios. The planners will develop deviations and work arounds to the optimum class product structuring and construction sequence to maintain the ship construction schedule. Keeping track of the lead ship networks, while still maintaining and relating to the class baseline will prove to be a challenging task. Also, as more and more detail is added to the networks, there is concern that a point may be

reached beyond which they are unmanageable. Only experience will provide solutions to these problems.

Other advantages which have been realized or anticipated as a result of this new dimension in construction planning include long range manpower forecasting, more precise and complete impact analysis of future changes, and better cost return data for future construction proposals. However, in the words of the Manager of Advanced Planning, "We've only started, we have yet to determine all of the benefits of these new systems."

CONCLUSION

The SEAWOLF program has introduced significant changes in methodology and deliverables into the design process. The benefits of these changes are now being realized in construction of the lead ship. The early returns indicate a large measure of success in application to construction. Digital data exchange is providing more accurate information, in many cases at an earlier time. Also, less effort is required to prepare it for direct use in construction. The SCD's and Planning and Sequence Documents provide the Shipbuilder with product-structured and planned information which simplify his task of construction planning. Tangible and positive evidence of these improvements can be seen at Electric Boat as the pace of SEAWOLF construction accelerates.

These positive results were not achieved easily, however. They have required substantial cultural change in the design force; reorganization and process change and the absorption of increased work load and responsibility for the Design Yards. These challenges are being met and the payoff is being realized.

FUTURE AREAS OF REVIEW

The changes implemented in the SEAWOLF program have not only generated successes, they have also shown potential avenues for additional improvements to the design and construction process. For example, the success of data exchange indicates the need to expand its horizon in future programs. Extension of the exchange to encompass all graphic data, and the closer linking of graphic and business data through efforts such as PDES, Navy Industry Digital Data Exchange Steering Committee (NIDDESC), IGES, and CALS, should be actively pursued. The SEAWOLF experience shows that it need not be an "all or nothing" solution. That is, data exchange can be implemented incrementally and selectively, in manageable groupings, and still achieve large measures of improvement.

Likewise, we must continue to seek ways to improve the methodology for providing design disclosure to the Shipbuilder. The SCD is a major step in providing the information in a form convenient to the builder rather than to the designer. But it need not stop there. With the ever increasing level of computerized design and data management capability, it may be possible to deliver the data required by the shipbuilder totallv in electronic form and eliminate the paper drawing as we know it. This would provide the ultimate flexibility for preparation of shipyard work packages by allowing the construction planner to select the relevant data and graphic views exactly suited to his construction methodology from the design data bases.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to the following Electric Boat people; Mr. Edward Greenberg, Mr. John Wallent, Mr. Robert Nowak, Mr. Victor Butsch, Mr. Robert scuillo, Mr. Barry Espeseth, Mr. Roger Cournoyer and Mr. Bernard Breen and NAVSEA people; Admiral Millard Firebaugh, Captain Jack McNamee, Mr. Robert Keane, Mr. Kirk Ryan and Ms. Terri Joyce who helped create this paper.

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Plister Hotel, Milwaukee, Wisconsin, August 21-24, 1990

Photogrammetry as an Advanced Planning Tool for Naval Shipyards

7B-1

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ABSTRACT

Photogrammetric technology captures dimensional data on systems' existing configurations. Photogrammetry is useful for determining the dimensional attributes of a system whose configuration has been modified and/or not recorded or updated. Knowing before execution of work begins the as-built structural conditions of systems on which work will be performed increases the shipyard's ability to plan a job efficiently, allowing the job to be completed in a timely cost effective manner. This can assure millions of dollars of elimination of rework and trial-and-error fit-ups and ensures enhanced product quality.

This paper will present several case studies in which naval shipyards have used photogrammetry prior to execution of work in order to effectively plan and accomplish the work more efficiently. Successes realized through the use of photogrammetric technology can be shared among all of the naval shipyards with great cost savings potential to the Navy.

BACKGROUND

Photogrammetric technology captures dimensional data on systems' existing configurations. Photogrammetric cameras are used on site to take pictures of the area of consideration with minimal disruption of the work force - most of the work is accomplished at the photogrammetric and CAD/CAM workstations. At the photogrammetric workstation, a measuring instrument is used to extract data from the photos, and a computer with photogrammetric software determines the dimensional data points. Resultant data can then be transferred to a CAD system to generate an engineered drawing. The data can either be two or three dimensional, and is not constrained by the complexity of the configuration. While Photogrammetrv is not a brand new, untried technology, many aspects of it have been automated to make it a fast, versatile, and accurate method of collecting dimensional data.

The extended uses for photogrammetry and its benefits are numerous. The following four categories represent diverse uses of photogrammetric technology:

1) Dimensional Attribute Determination. Photogrammetry is useful for determining the dimensional attributes of systems whose configurations have been modified and/or not recorded or updated. Photogrammetry can be used effectively to aid in producing needed drawings for parts where a part drawing is unavailable.

2) Structural Verification. Large scale naval ship repair or alteration jobs sometimes require tests to verify certain structural conditions. Collecting data necessary for measurements on a substantially sized component can be very labor intensive, costly, and subject to inaccuracies. Photogrammetry is an excellent tool for verifying structural conditions. The high degree of accuracy possible makes photogrammetric technology a very reliable method of obtaining precise measurements. As an example, Charleston Naval Shipyard has performed numerous tests to verify photogrammetry as a method for measuring full and partial submarine hull circularities.

3) Advance Planning Tool. One of the most important values in photogrammetry is in its use as an advance Planning tool. Knowinq before execution of work begins the as-built structural conditions of systems on which work will be performed increases the shipyards* ability to plan a job efficiently, allowing the job to be completed in a timely, cost effective manner. This can save millions in material and manpower by assuring

first time quality and the elimination of rework and trial-and-error fit-ups.

Photogrammetric technology as an advance planning tool would also be extremely valuable in the design of ship alterations. Planning yards that are responsible for developing implementation plans for major alterations during an availability could employ photogrammetric technology to identify ships' existing conditions in areas affected by the alteration, allowing increased pre-planning capabilities.

4) Information Source. In addition to definition of structural conditions, photogrammetry can also be useful in facilitating inspection procedures, and providing permanent records and historical backup data, often useful to check results, gather additional data at any time, or as informational data for technical or litigation issues.

The following case studies illustrate the varied applications afforded by the use of photogrammetric technology in naval shipyard repair and alteration projects.

DAVITS FABRICATION PROJECT

The use of photogrammetry to determine unknown dimensional attributes is an important application of photogrammetric technology.

Naval ships' components and compartments are often modified during overhaul and repair, but subsequent changes to the drawings are neglected: as a result "as-built" drawings are not indicative of "as is" conditions, making the planning and execution of work difficult and costly, and often resulting in hundreds of manhours of rework. Further many projects require the duplicate manufacture or repair of a system to which no documentation exists. Currently no method exists to capture the "as-is" condition of system configurations, other than costly and labor intensive manual measurements and redrafting.

In January 1988, Charleston Naval Shipyard was faced with this problem. DDG-45 whale boats' and DDG-39 personnel boats' original davits were determined to be made of the wrong material and had to be refabricated and replaced using proper material.

Old plans for the original davits dated back to 1956 from Welin Davit and Boat Division. Many critical changes had been made to the davit, but formal revisions and modifications to the original part drawings were neglected. These changes included additional designs not included on the original drawings like angle of trackway, shapes of heads, and additions such as tensioning devices, tension guides, tension sheeve supports, and stops. Therefore, complex angles and configurations, and sizes of other structures that had been added were unknown.

The first davit for the whale boat was recreated manually; sizes were extrapolated from templates created at the boat, and from davits removed from the boat and brought to the shop for comparison. This process was very time consuming; because the davits are very large, "tracing" templates was awkward, and templates were difficult to handle. Further, obtaining accurate dimensions was impeded by other structures that "stick out" in the way, (especially for angles, one to two degree accuracy is important). Finally, and most obviously, traced templates can not provide three dimensional data - only a two dimensional figure could be created with the template. All third dimension components were measured by hand and noted.

Charleston Naval Shipyard decided to use photogrammetry to solve these problems. The photogrammetric specialist had mold loft experience; this proved to be a key factor in correctly determining what data to capture in order to ensure complete and accurate detailed photographs. Some of these targeted key areas provided critical dimensions for locations of all pivot points, foundations, the angles of the sheeves in relation to the head, the location of sheeves on the head, the perimeter of the head, the angle of the trackway and its length, and location of stops. Additionally, the specialist made specific observations, noting additional features to investigate during ultimate data analysis using CAD/CAM.

During the actual photogrammetric survey, the targets were attached to the davits on the critical positions to define major features as described above, and photographs were taken primarily using the convergent method of photogrammetry (Figure 1). A few stereo photographs were also taken to allow dimensioning of smaller details. At this point the photogrammetric process for davit replacement moved off the ship and into the shop.

Back in the shop, the photographs were developed and photogrammetric three dimensional data were extracted from the photographs. These data were then used to produce a CAD/CAM part

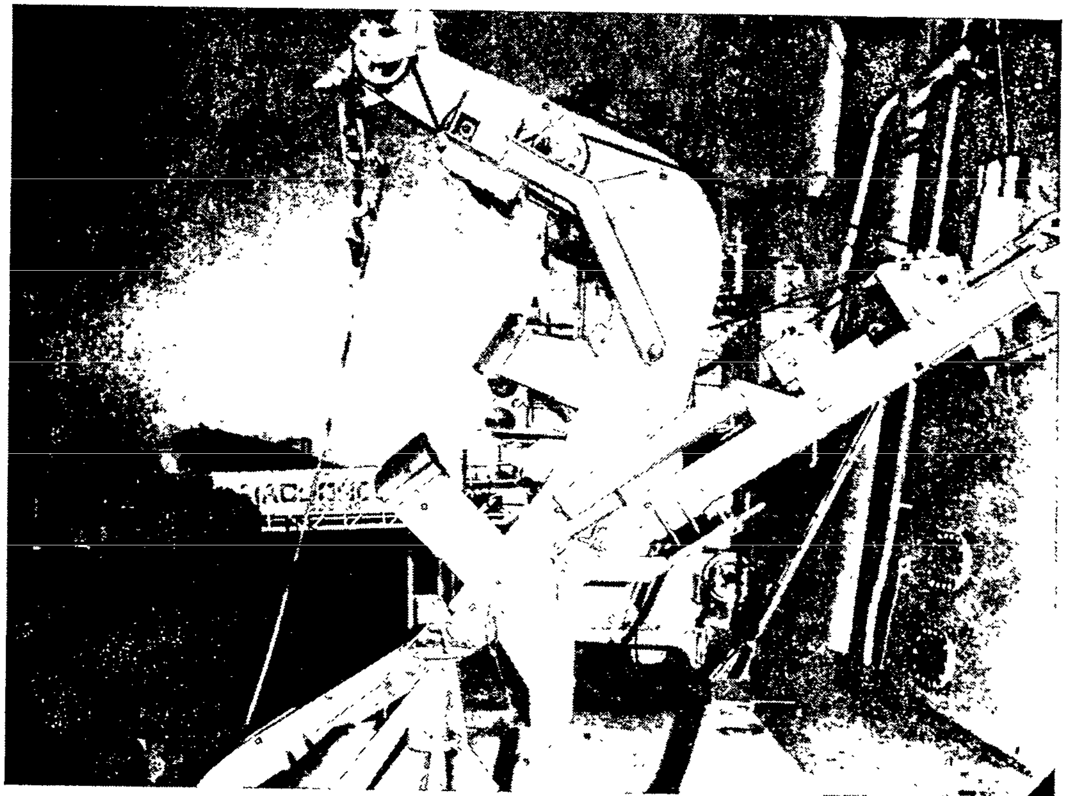


Figure 1. DDG – 639 PERSONNEL BOAT DAVIT (AFT SIDE, LOOKING FORWARD) Note small black and white targets on critical attributes.

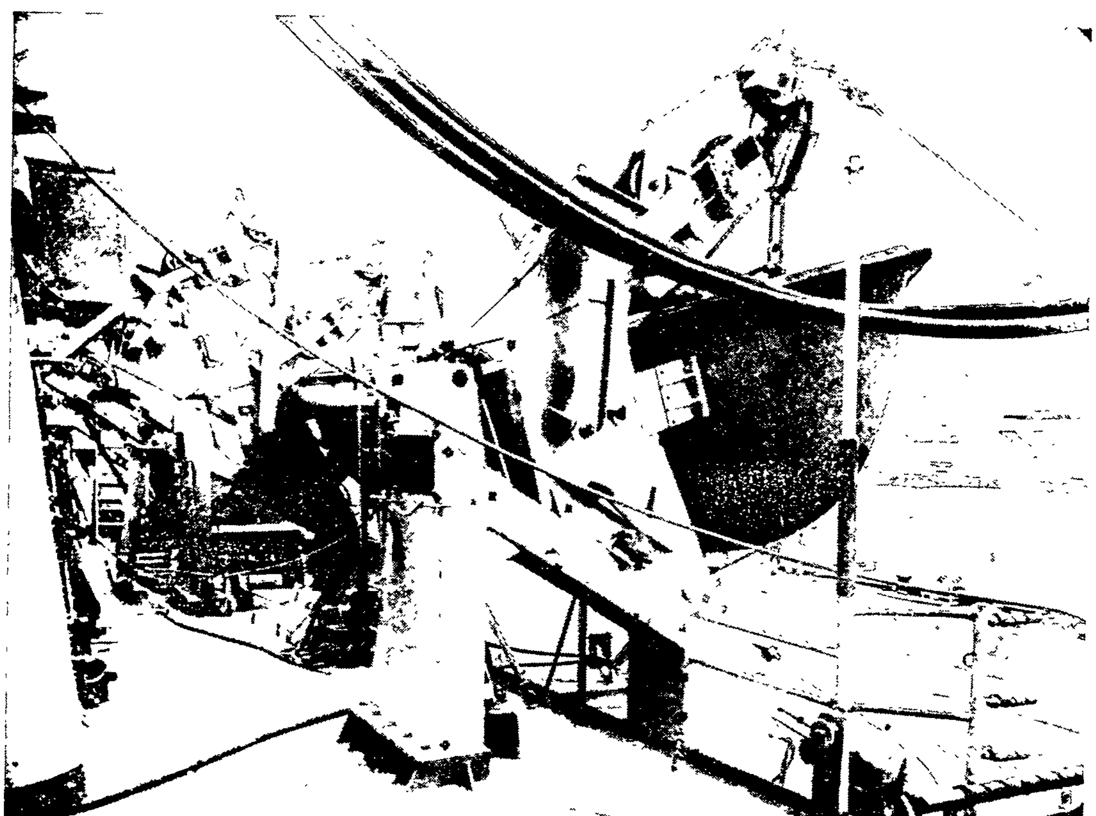


Figure 2. DDG-45 WHALE BOAT DAVIT (FORWARD SIDE. LOOKING AFT) Note targets on critical attributes.

drawing in order to ultimately generate a flat pattern template from the photogrammetry data.

The use of photogrammetry on the development of the whale boat davits was a success. Subsequently, a similar process was employed to create the davits for the DDG-39 personnel boats, with a few changes. The aft side of the head of this davit was found to be completely different from the forward side of the head (Figure 2). Therefore, photographs of both sides of the davit were taken to ensure that all dimensional attributes were captured to recreate the davit. Further, unlike the whale boats which were photographed mostly for convergent analysis, this project was shot primarily in stereo. Although this affords a lesser degree of accuracy (1/32 inch), it also requires fewer targets, and most of the needed data can be extracted from the pictures without targets.

Both of the davits projects were successes. Rework was avoided because measurement methods increased the accuracy of the templates; using photogrammetry eliminated the cumbersome, time-consuming old method. Finally, mechanics were able to recreate the new davits while the ship was gone, and without removing and bringing an old davit into the shop. When the boat returned, the new davits were installed, allowing the ship to remain operational throughout the process. Therefore, Charleston Naval Shipyard succeeded in effectively employing photogrammetry as a tool in dimentional attribute determination.

PHOTOGRAMMETRIC HULL CIRCULARITY MEASUREMENTS

Recognizing the structural verification advantages of photogrammetric technology, Charleston Naval Shipyard has been interested in the application of photogrammetry to hull circularity measurements. With the revision A of MIL-STD-1688 (not yet issued), the optical squares method currently used at Charleston, and some other methods currently employed by other naval shipyards will most likely become obsolete by their inability to meet the accuracy and repeatability requirements the revision will require; photogrammetry, however, can provide up to 1/64 inch to 1/32 inch accuracy, depending on camera stations and the photographic angles. Therefore, Charleston Naval Shipyard initiated a test concurrent with the compartment removal project to verify photogrammetry as a method for measuring full and partial circularities. Based on this test methodology, the Production Industrial Engineering Division at Charleston Naval Shipyard is preparing a process instruction for the use of photogrammetry in measuring hull circularity for all naval shipyards. A clearly defined procedure is necessary in order for the process to be approved by NAVSEA in accordance with the existing MIL-STD, and the upcoming revision.

According to the MIL-STD, circularity measurements are necessary at all hull locations subjected to frame cuts and hull penetrations during ship repair and alteration. The first phase of conducting a photogrammetric hull circularity survey involves planning the job. Major obstructions to the view of the area to be surveyed, such as staging, platforms, or enclosures must be planned to be removed, or the photographs must be shot around the obstructions. All targeted points must appear in at least two photographs, and four to five photographs are recommended "just in case", but singularly missed targets are not a problem and can be easily interpolated to approximately 1/32 inch. Overlapping photograph shots is recommended in order to "tie" adjacent shots together. Specifically, double-faced targets must be included that "connect" the port and starboard side shots.

During set up of the actual photogrammetric survey, circumferential lines perpendicular to the main axis of the hull must be scribed. Targets are placed every five degrees along the line. (For reference, topside is considered 0 degrees, and keel is at 180 degrees). In the keel area between 150-210 degrees, radial offsets of known lengths are used with double faced targets at their endpoints for capturing dimensional data at the keel in both port and starboard shots. Finally an object of known external measurements must be captured in the photographs to establish the scale.

Having planned the shots, and stuck the targets to the hull in the appropriate places, photographs are taken using photogrammetric cameras from planned stations, including overhead shots from zero degrees using an overhead crane. Because the convergent method is preferred for photogrammetry, multiple shots of the area in question from various angles are required for accurate triangulation.

Once the pictures are developed, the original negatives are measured.

Two dimensional photomeasurements are turned into three dimensional coordinates of the targets via software designed to perform photogrammetric triangulation. The raw data coordinates corresponding to each target, input to a CAD system, are developed into a mean circle which is then compared to the actual expected contour. Deviations are calculated every five degrees and a best fit circle is developed in order to determine the measured circularity of the hull (Figure 3).

Photogrammetry, as applied to structural verification, particularly in the case of hull circularity measurement, will greatly benefit the naval shipyards by replacing the obsolete methods, which are generally very labor intensive and sometimes suspect in their accuracy, with an advanced, reliable state-of-the-art method of determining a hull's roundness characteristics.

CNSY PRESSURE HULL
POST CIRCULARITY
FWD END 6"AFT FR 59
SSBN 619 INACTIVATION
EACH INCREMENT EQUALS I IN.

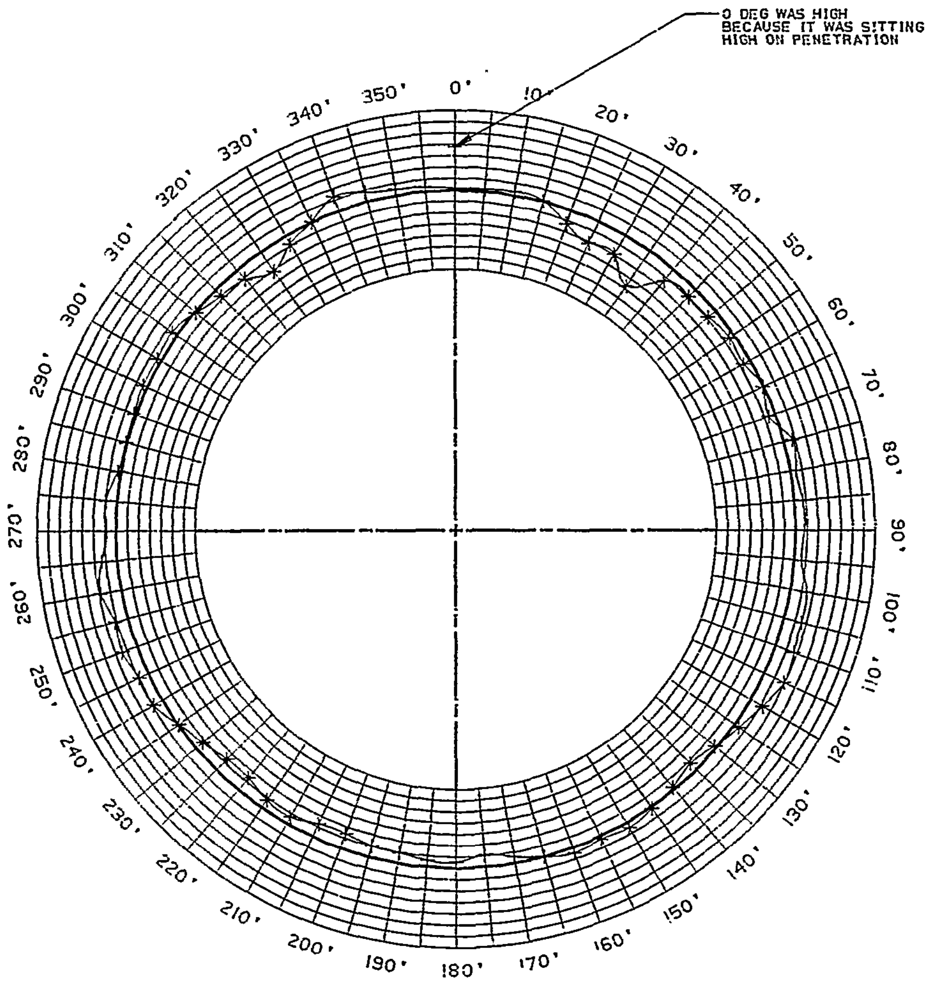


Figure 3. HULL CIRCULARITY CONTOUR PRINTOUT Actual printout of SSBN 619 circularity 6 inches aft of frame #9 depicts mean hull contour (solid dark line) and actual measured deviation in 0.1

COMPARTMENT REMOVAL/BULL JOINING

Charleston Naval Shipyard implemented photogrammetric technology on a specific project for the SSBN 619. Charleston Naval Shipyard was required to remove the missile compartment on SSBN 619 in a very short period of time. Charleston Naval Shipyard drydocked SSBN 619 and removed the compartment nearly two to three weeks ahead of schedule. In this case, Charleston employed photogrammetry as an advanced planning tool.

On previous jobs of this nature using traditional methods, after the' rough cuts had been made and the compartment removed, the exposed aft and fore ends were pulled to within 12 inches of one another. Each end was then manually measured, compared to the other, and cut iteratively until the fore and aft ends matched. at which time a final pull was made to join the two ends for welding. This method was very labor intensive, posed a great fire risk, and required rework as the process methodology.

Charleston Naval Shipyard proposed to use photogrammetry to eliminate the need to manually rework each end until a match was achieved, and to reduce the entire operation to a single pull to join the two ends together.- The method is outlined as follows:

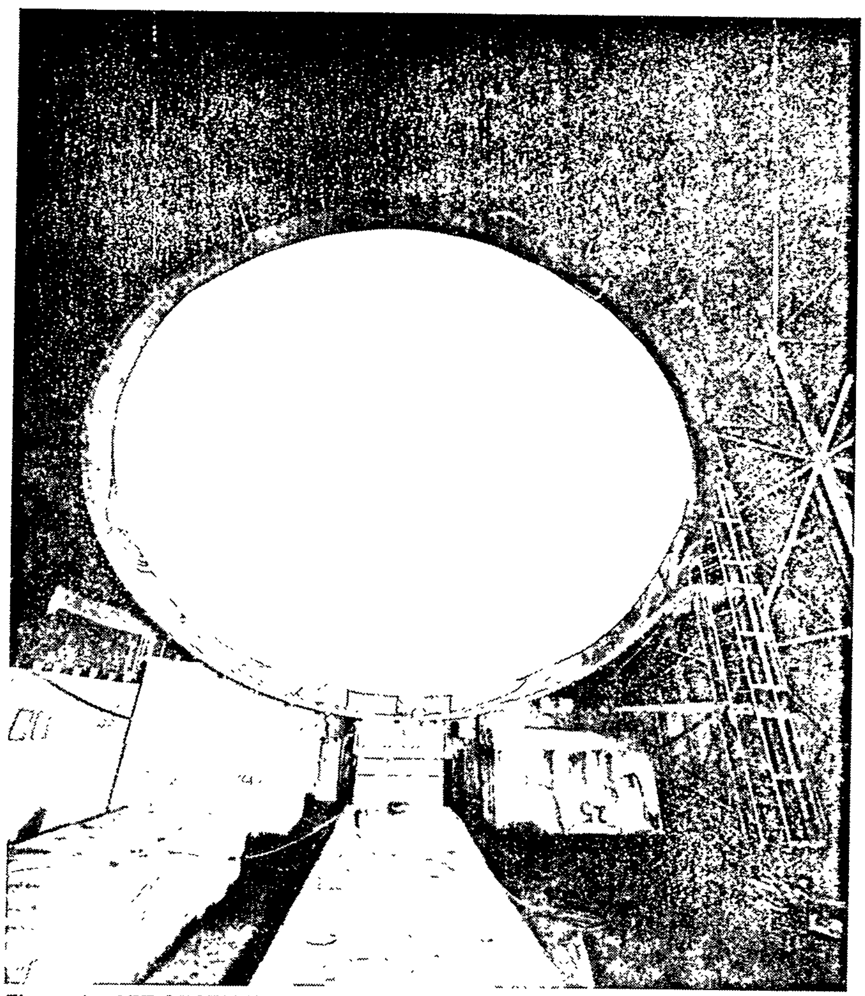


Figure 4. AFT SECTION SSBN 619 AFTER MISSILE COMPARTMENT REMOVAL

Sketch depicts aft exposed end after removal of missile compartment. Note placement of photogrammetric targets along the mating face.

Shipwrights began by scribing lines about the hull to mark the initial cuts. The missile compartment was rough cut out in segments. As soon as the aft end was exposed, welders trimmed neatly to the scribed line and weld prepped. A photogrammetric survey was subsequently made of both the aft (prepped) and forward (unprepped) surfaces, with targets every 2 1/2 degrees on each end. (Figure 4) The data from the survey, entered on CAD/CAM, was compared and a template that matched the prepped surface was developed for the unprepped surface. Once the unprepped surface was cut to the prescribed dimensions, it was expected that one pull would be sufficient to join the surfaces for welding.

The Structural Group at Charleston Naval Shipyard attempted to eliminate the second pull required to join two hull halves using a traditional method by changing the method to include photogrammetry. Although this first attempt did not result in a single pull as anticipated, this initial experience in joining hull halves using photogrammetry has provided valuable lessons learned. Analysis of the hull fit indicated up to 1 13/16 inch deviation at the worst point (only 1/4 inch is allowable for welding). Problems were attributed to the following:

During photogrammetric measurements, analysts assumed that shipwrights reference lines were accurate; it was not emphasized that scribed line accuracy should be no less than +/- 1/8 inch. The reference lines were adequate for hull circularity measurements, but not accurate enough for the fit-up application. One scribed line followed a weld-butt on the hull that dog-legged near the top around an obstruction, creating a marked difference on port and starboard sides. This caused the cuts to be angled (0.3 degrees on starboard side and 0.1 degree on port side. Average 0.2 degrees = 1 1/2 inch deviation) These minute angles were not detected during the photogrammetric analysis, but could have been if a reference line, common to both halves, had been established during the planning phase. Further, there was no monitoring of ship's changing structural conditions to determine shift of ship after cut. (The impact of this issue is not known.)

Structural group personnel analyzed the situation and developed two important corrections to the procedure that must be established in order to ensure future successes. First, scribed reference lines must be assuredly shot to an accuracy of +/- 1/8 inch. The lead shop will properly inform assist shops of this requirement. Second, and most importantly, a reference line, common to both halves, must be established in the photogrammetric shots in order to determine if any deviation exists. Because of the accuracy provided by photogrammetry, even small deviations can be detected if this reference line exists on the photographs - regardless of the location, the sums of the angles on the straight line must equal 180 degrees. Different methods may be used to accomplish this, including simulation of the track in place between the two halves, or shooting the photogrammetric data with the track in place.

PHILADELPHIA BOW REPLACEMENT PROJECT

Philadelphia Naval Shipyard used photogrammetry as an advance planning tool in a project slightly different from the compartment removal/hull joining project at Charleston Naval Shipyard. In 1985, during deployment in the Sea of Japan, USS Kitty Hawk (CV-63) was struck by a submerged Soviet submarine, causing significant structural damage to the bow of the ship. An estimated 99.25 tons of concrete were poured into various bow compartments to seal cracks in the hull caused by the collision. This allowed the ship to remain operational until the next scheduled overhaul availability.

Upon USS Kitty Hawk's arrival in Philadelphia Naval Shipyard for a scheduled Service Life Extension Program (SLEP) overhaul, engineers determined that the entire concrete filled damaged bow section would have to be replaced. This included a section 11 feet wide, 11 feet high, affecting 5 frames forward to aft approximately 21 feet (Figure 5). This section was cut from the ship and removed, and Philadelphia Naval Shipyard was faced with fabricating a replacement bow.

The Philadelphia Naval Shipyard Zone Technology Office chose photogrammetry as the preferred method for determining the dimensions necessary to construct the replacement bow section, and as a measure of ensuring a first-time quality fit-up of the new bow to the ship. This application of photogrammetry as an advance planning tool was a success for Philadelphia Naval Shipyard.

For this project, photogrammetric surveys were performed twice. The first photogrammetric survey was performed on-site 16-18 May 1988. Data were collected at the ship to

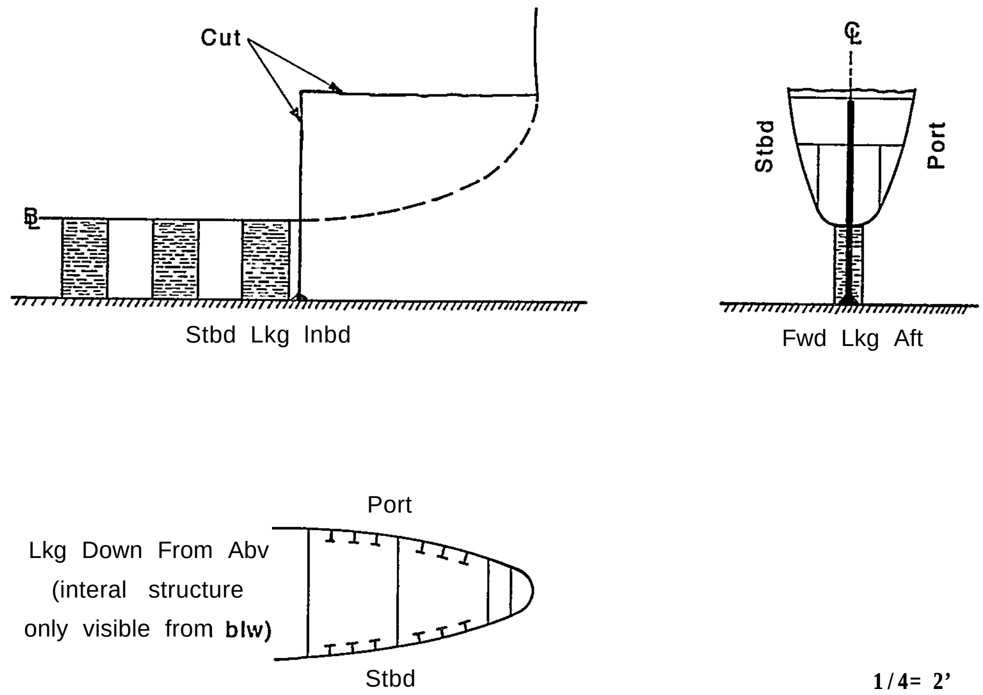


Figure 5. DAMAGED KITTY HAWK BOW SECTION

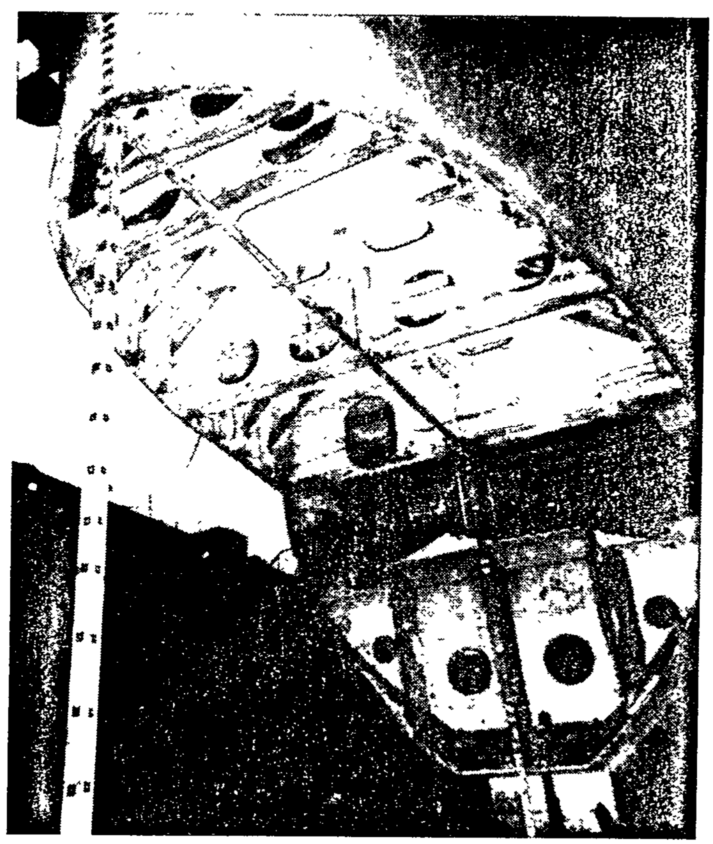


Figure 6. KITTY HAWK WITH BOW CUT AWAY The first of two photogrammetric surveys for the bow project was performed on this section. Note targets along cut lines and reference points.

determine what the dimensions of the mating faces of the replacement bow section should be; the challenge was to fit the perpendicular planes simultaneously (Figure 6). The photogrammetry team targeted structural members, scribed lines, and reference lines: the convergent method was used to capture targets at six inch intervals along the cut lines. The data were extracted from the photographs, translated, and rotated into the ship's coordinate system. The resultant raw data were sent to Philadelphia Naval Shipyard shop 11 mold loft personnel to be converted to graphic format on CAD. The outline of the dimensional attributes of the actual cut out section on the ship was compared to the offsets on the existing as-built drawings. This comparison exposed inconsistencies between the dimensions on the drawings, and the photogrammetric data representing the existing conditions: Philadelphia Naval Shipyard chose to accept-the dimensions as developed using photogrammetry. Thus, based on the photogrammetric data, building changes to bow construction were made.

Large complicated fabrication jobs such as the bow construction which are sometimes subject to small mistakes in workmanship are invariably amplified due to the large size of the overall project. In order to verify that the newly constructed bow would properly mate to the cut away section at the ship, additional photogrammetry of the ship's newly fabricated replacement bow was performed to ensure the first-time correct fit-up and alignment of the replacement bow section to the ship. The second photogrammetric survey was performed 19-20 September 1988 on the newly constructed replacement bow mating faces (Figures 7a and 7b). Resultant data from this survey was compared to the data extracted from the first photogrammetric survey of the actual dimensions of the ship; slight deviations were discovered, and minor in-shop adjustments were made to the replacement bow before fit-up. Finally, the new bow was transported to the ship in drydock. Not surprisingly, the bow fit the ship without requiring rework.

The Kitty Hawk Bow Replacement efforts were not only structurally successful: they also helped to prove the value of photogrammetry, and more importantly, to build the shipyard's confidence in the industrial applications of photogrammetry.

CABLE REEL ASSEMBLY FOUNDATION PROJECT

In order to accommodate a cable reel assembly for new equipment being installed on navy frigates, shipyards were tasked with completely converting what used to be a navy personnel weight room to outfit the SHIPALT. This included installing an 8' x 12' foundation to support the cable reel assembly. Based on experiences learned from a private shipyard that had to rip out the newly installed foundation completely several times and start again because of misalignments, Charleston Naval Shipyard decided to try a new approach: they used photogrammetry to preplan the job.

The challenges in successfully completing this project are threefold: first, the contour of the bottom of the foundation must match deck deformations; second, the top of the foundation must be prepared to accommodate the cable reel assembly; and third, the reel must line up with the fair lead in the ship's hull.

In normal operations, without the benefit of photogrammetry, patternmakers develop a model on CAD/CAM for 'the general specifications of the foundation and generate a pattern from which the shipfitters fabricate the foundation. The prefabricated foundation is then taken to the ship. In the compartment at the ship the foundation is fit to the deck; where it does not fit satisfactorily for welding purposes, it is rigged and raised from the floor to be cut. This process continues until an acceptable match is created between the mating faces of the bottom of the foundation and the deck. The foundation is then welded to the deck. Next, machinists begin the process of machining the top of the foundation to install the assembly with respect to proper alignment with the fair lead.

The process changes considerably using photogrammetry. After patternmakers develop the pattern of the foundation, and while the shipfitters are prefabricating the foundation, a COPY of the pattern is taken to the ship's compartment, and the pattern is center-punched onto the floor. (Figure 8) Photogrammetric targets are placed along the center-punch lines the Water lines, to the fair lead and along all deformations on the deck where the foundation must match to the deck, thus capturing the contours of the floor over weld butts and deck curvatures. After all of the targets are set and numbered for identification, photographs are taken using photogrammetric cameras. The

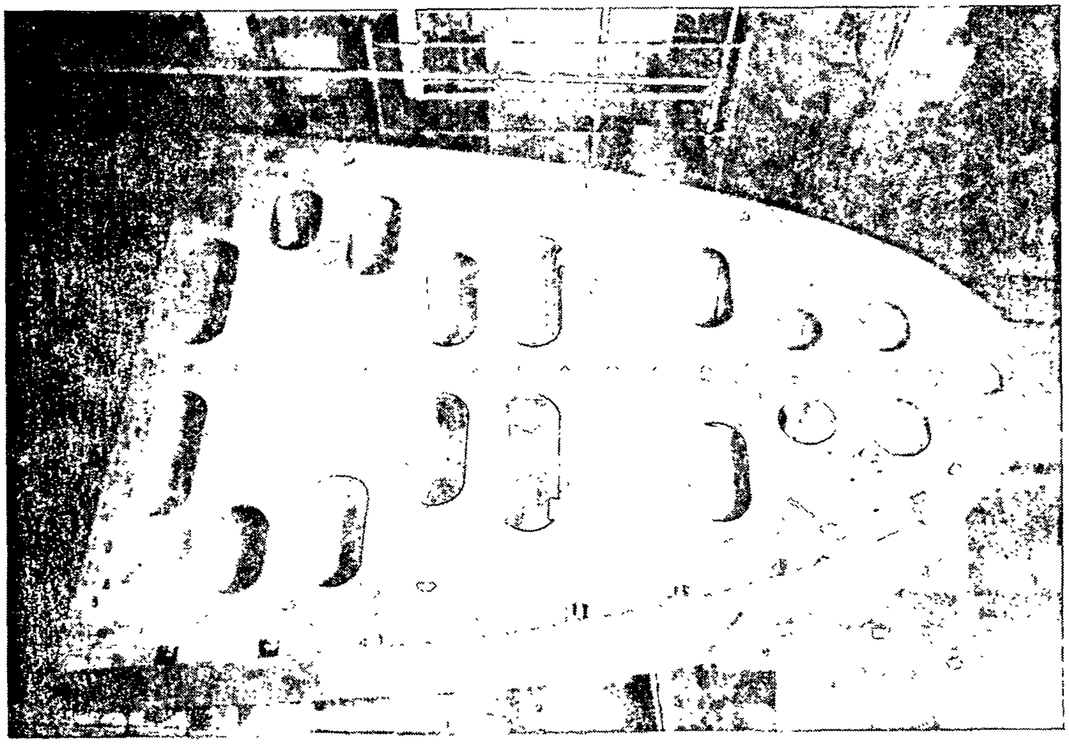
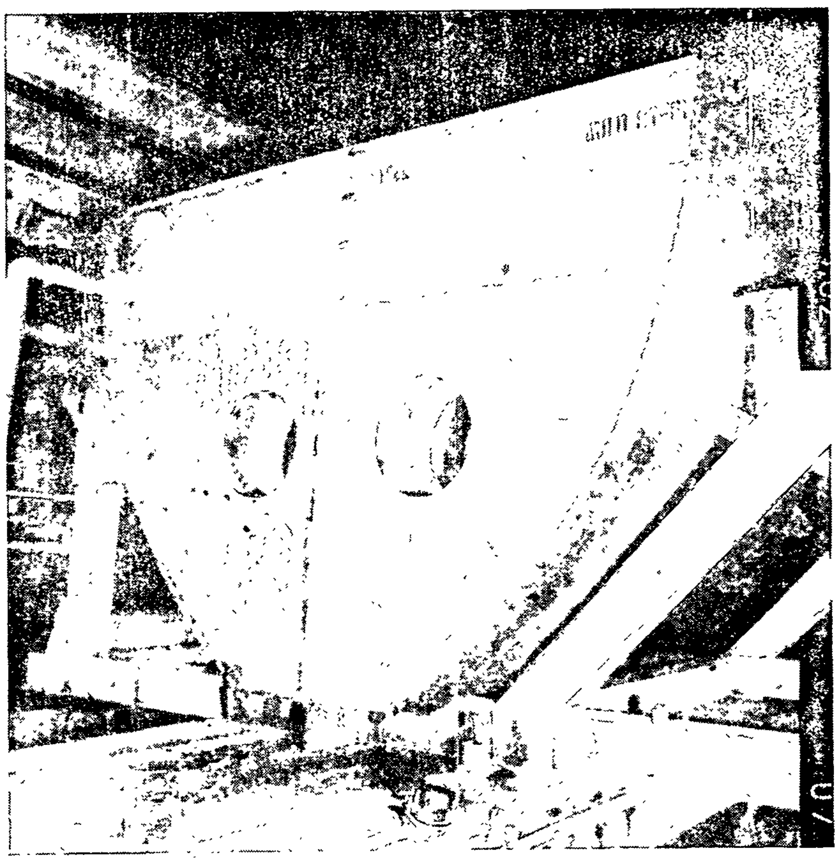


Figure 7a. NEWLY CONSTRUCTED KITTY HAWK BOW (TOP VEIW) The second of **two** photogrammetric surveys for the bow project was performed on new bow section. Note the reference targets used to check the dimensions.



FORWARD)

Figure 7b. NEWLY CONSTRUCTED KITTY HAWK BOW (AFT LOOKING

convergent method of photogrammetry is used, with photographs taken from nine different photostations in the compartment. The set up and photography takes exactly two hours to perform (not including initial targeting performed by the mold loft-personnel). The film is developed immediatelv to determine if all points are captured, and to be sure no shot needs to be retaken. At the photogrammetric workstation, three dimensional data are extracted from the photographs. Charleston Naval Shipyard mold loft personnel modify the original CAD model of the foundation using the three dimensional photogrammetric data. This model is used to develop templates to properly center-punch and machine the foundation in the shop to fit the ship's deck (mating the bottom of the foundation to the deck), to accommodate the cable reel assembly that would be placed on the foundation, and to properly align the entire foundation, and its associated assembly, with the fair lead. This in-shop machining took only two men, two shifts, or 32 manhours, vice 500 manhours allotted for on-board grinding necessary using the conventional method.

After only forty five minutes rigging the completed foundation into the compartment on the FFG-40 (the first such project), it mated perfectly with the deck - no rework or on board machining was necessary. (Figure 9) Further, the alignment deviated only +/- 6 minutes fore to aft, and +/- 3 minutes port to starboard. Finally, the foundation was welded, using control welding in order to discourage heat warping and deformation.

A total of six other shipyards have attempted this process using conventional methods, and each has failed to be within tolerance on the first attempt at fitting; Charleston Naval Shipyard has succeeded the first time on each of three ships using photogrammetry. Photogrammetry eliminates the need for shipboard rigging and machining for fit-up to the deck, and on board machining the top of the foundation to accommodate the assembly. Using the conventional method, costs are estimated at approximately 1531 manhours. The photogrammetric process is estimated at 1082 manhours (including control welding). Therefore, total savings with respect to the operations that were eliminated, and considering the machining and photogrammetric survey added, are conservatively 449 manhours, or about $20990 per ship. These figures do not include the elimination of rework which figured prominently into the cost of the SHIPALT at the other six shipyards; based on the rework data available on

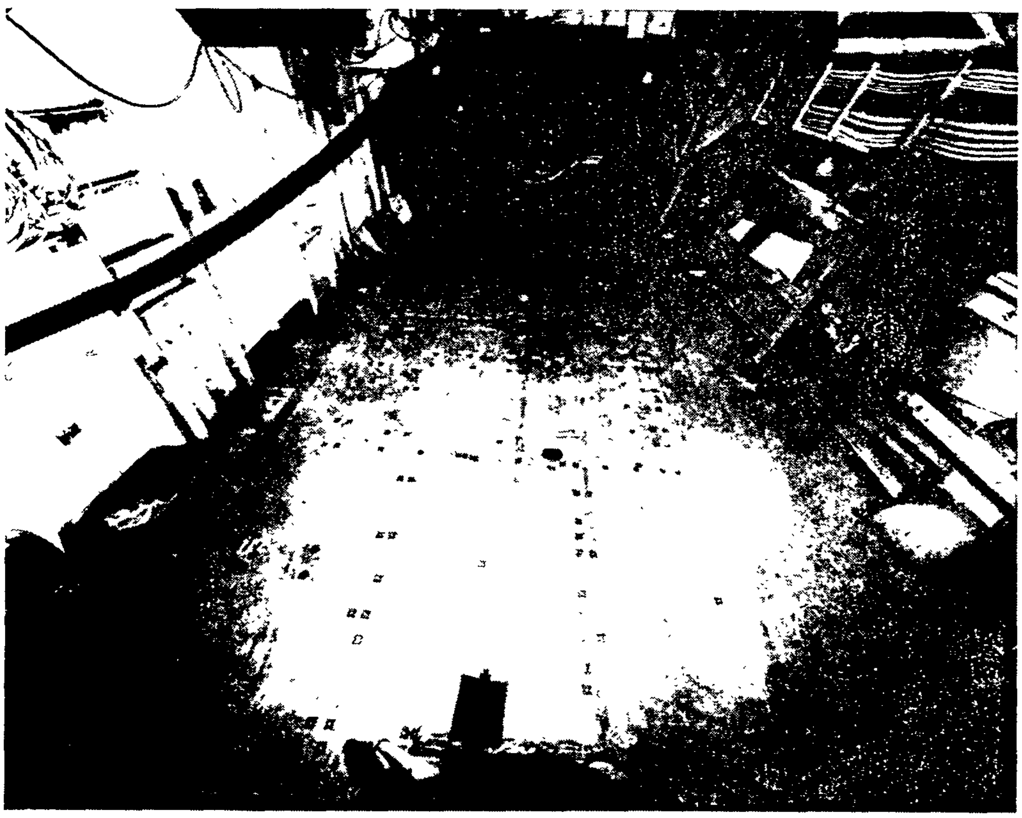


FIGURE 8. TARGET LAYOUT FOR FOUNDATION INSTALLATION PROJECT.

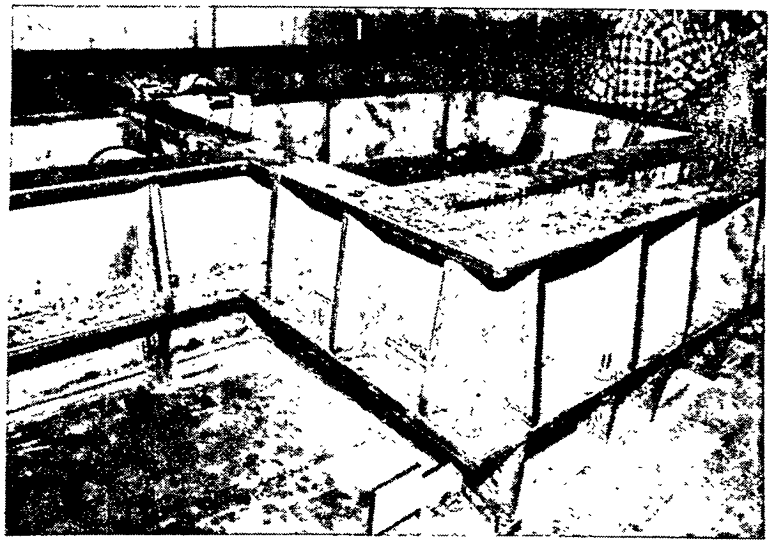
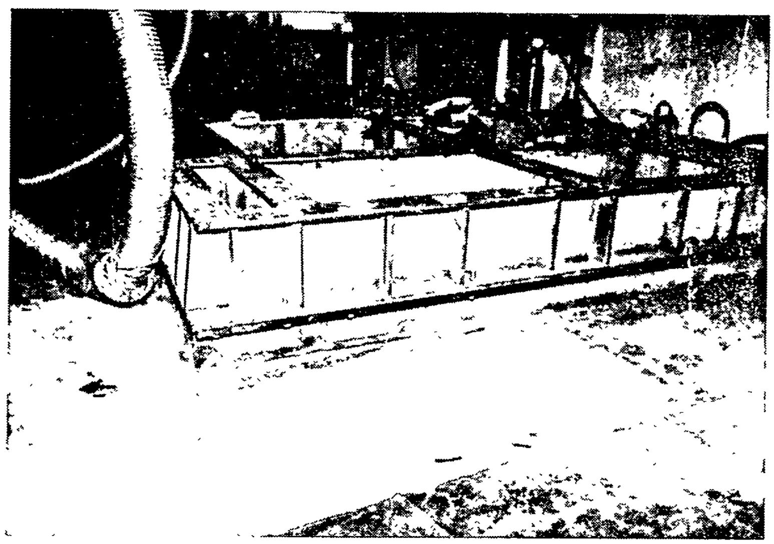


FIGURE 9. (TOP AND BOTTOM) FOUNDATION (WITH STRONGBACK) INSTALLED.



those attempts, it can be estimated that rework time would have been 1.5 times the original manufacturing time, 2297 manhours or $107,385.00 per availability. Charleston Naval Shipyard will complete six such SHIPALTS at a savings, including rework savings, of $770,250.00 for this application.

FAIRING ALTERATION PROJECT

Charleston Naval Shipyard was tasked to perform analteration on USS NARWHAL (SSN 671) such that a fairing enclosure to house equipment would be attached to the topside aft of the hull of the boat. The fairing had an egg-shaped metal framework, and was to be covered with glass reinforced plastic. In this project, the contour, shape, and framework of the fairing must match the surface contour, shape, and taper of the hull, and the frames of the boat. To further confound the problem, Charleston Naval Shipyard was experiencing difficulty in getting a contractor to bid on the installation of the glass reinforced plastic (presumably because the job appeared to be too difficult); the shipyard hoped to entice bidders by offering the completed frame for in shop work rather than for on-site work in the drydock.

Charleston Naval Shipyard decided to use photogrammetry in order to map the conditions of the shell (the

surface contours and shell shape of the hull). The fairing was to cover twenty-eight frames. Thus, photogrammetric targets were placed every 12 inches on the girth of the hull where the fairing intersects the hull along the frame lines and the conical section weld seams. Targets were also placed to establish reference planes. An established waterline formed the horizontal plane used to reference the height; the centerline referenced port and starboard planes, and frame lines referenced fore and aft planes.

Eight photostations were established to capture the data. The photographs were developed and the 3-dimensional data were extracted from the photographs. As with previously discussed projects, the data was entered onto the CAD/CAM system. The mold loft expert made adjustments to the data in order to obtain the "best fit" arc to the data points. Also, the contour of the outboard edges of the fairing that intersect with the hull had to be faired and then developed by the Loft from designed offsets. From the CAD/CAM data, one template was made for each frame structure on the longitudinal fairing, and for the final cut on the supports.

While quality of the alteration is greatly increased using photogrammetry, the greatest savings come in the reduction of manhours, and the reduction in the schedule. This process can be performed conventionally, without the use of photogrammetry, in one of two ways. First, the frames would be constructed in the shop with material left on each frame structure. These frames would be taken to the boat one at a time and cut to fit the shape and taper of the hull and alignment with the previous frame. In the second conventional method, templates would be developed through extensive manual measurements in order to construct the frames in the shop. Both of these methods are extremely labor intensive, and subject to human and process error that results in high rework costs.

Using photogrammetry, the dimensional data is easily obtainable and readily available, eliminating the need for manually creating individual templates; the entire structure can be fabricated in shop, with first time quality, eliminating the need for rework, costly extended rigging services, and on-board grinding. Finally, the structure can be shipped before installation on the boat, with the supporting dimensional data if necessary, to the contractor responsible for adding the glass reinforced plastic, thus assuring lower costs and higher quality on the part of the contractor, and reduced trade interference in the drydock.

SUMMARY

Photogrammetry can be used in a variety of shipyard applications ranging from hull circularity measurements, or assuring the alignment of large compartmental bulkheads, to jobs as small as single component designs, such as valves.

Photogrammetry projects are excellent applications of existing technology. Naval shipyards are recognizing the value of photogrammetry, and are actively encouraging additional naval shipyard personnel to pursue other applications of this technology. Photogrammetry's benefits, both for these and other projects can be shared among all of the naval shipyards with great cost savings potential.

ACKNOWLEDGEMENTS

The authors would like to thank the following who have contributed to the documentation of these case studies:

John F. Kenefick, Photogrammetric Consultant, Inc.

Billy Hughes, Charleston Naval Shipyard Mold Loft

Preston Simons, Charleston Naval Shipyard Mold Loft

Mitchell King, Charleston Naval Shipyard Industrial Engineer

LCDR Mark O'Hare, USN, Philadelphia Naval Shipyard Zone Technology Office

LCDR Barry Munro, Canadian Forces, Philadelphia Naval Shipyard Zone Technology Office

Bill Murray, Philadelphia Naval Shipyard Zone Technology Office

Joe Krulikowski, Philadelphia Naval Shipyard Design Engineer

Beverly Cowart, Charleston Naval Shipyard Industrial Engineer

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APPENDIX

Photogrammetric Methods

This paper refers to the use of two different methods of photogrammetry:

1) Convergent Method employs single photographs taken from variously angled positions of the same scene, or of more than one scene tied together with common data points captured in adjacent scenes. Pre-selected targeted data points are computer processed using an xy digitizer and complex triangulation software. The convergent method can easily achieve up to 1/64 inch accuracy for many shipyard applications.

The convergent method affords two to three times greater accuracy than the stereo method. Using the convergent method, there are no restrictions on shot locations or set-up: pictures can be taken from any accessible vantage point. However, unlike the stereo method, targeted data points must be planned before photographs are taken, and only pre-defined, discrete data points can be measured.

2) Stereo Method employs only two photographs of the same scene, or portion thereof, taken from near parallel photoaxes. This method allows free selection of the quantity of data points and the density of detail without preplanning targeted positions. Allows selection of data points after shots are taken using elaborate stereoviewer equipment. The stereo method can achieve up to 1/32 inch accuracy.

Although the stereo method affords a lesser degree of accuracy than the convergent method, it is preferred in situations where the measurement of contours and profiles is necessary, where targetting is difficult or the number of data points is very large. Because the use of this method is constrained by camera placement requirements in order to maintain parallel axes on the two photo shots, its applications in many shipyard industrial Situations may be limited by the presence of physical obstructions in the work environment.

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Plister Hotel, Milwaukee, Wisconsin, August 21-24, 1990

Photogrammetry, Shipcheck of USS Constellation (cv64) Arresting Gear Engines 7B-2

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ABSTRACT

Arresting gear engines are large heavy pieces of machinery which are costly to replace because of expensive repairs and modifications to existing decks. These costs can be avoided and the units installed in a more timely efficient manner if the photogrammetric process is used. This article outlines the methods and techniques for using photogrammetry as a planning tool. It also demonstrates the practicality of collecting dimensional data from existing ship structures and foundations and using this data directly in the manufacturing phase of the equipment.

BACKGROUND

As part of the Aircraft Carrier Service Life Extension Program (SLEP), the arresting gear engines which are part of the system used to absorb the energy from landing aircraft are replaced with modern updated versions. This work is accomplished under Ship Alteration (S/A) 6790. In the past, arresting gear engines were maneuvered into position several times during fit-up. Because these units weigh over **31750** kg (70,000 pounds) each, this is a difficult process. The precedent for using photogrammetry to locate arresting gear engine bolt holes was set when successfully used on the USS KITTY HAWK (CV-**63).** On the CV-63 photogrammetric data from both the deck and the arresting gear engines were compared so that the arresting gear engines could be positioned to avoid extra handling. It was an outgrowth of this previous success that encouraged a more integrated approach when using photogrammetry on the USS CONSTELLATION (cv-64). Investigations during the advanced planning revealed that the existing engine base and the new engine base were nearly identical. It was then determined that if the existing bolt hole pattern of each engine could be used as a template for the soon to be manufactured engines, then expensive and time consuming deck repairs could be avoided.

PAST REPAIRS

On the older aircraft carriers, the gallery decks are made of special treated steel (STS) plating, usually about 19 mm **(3/4** of an inch) thick. Older STS plate is very brittle making it extremely difficult to accomplish weld repairs. For example, on the USS INDEPENDENCE **(CV62),** it was necessary to make extensive deck plating replacement because of cracks created by repair welding.

Each of the four arresting gear engines are held down by 266 bolts. These are **22.23** mm **(7/8** inch) bolts in a clearance hole of **23.81** mm **(15/16** of an inch). heck repairs, in the past, have included plug welding the existing bolt holes after the existing engines had been removed. These plug welds were then required to pass non-destructive testing. Then, the new engine was lowered into the space (gallery deck) from the flight deck above, and used as a template to determine the location of the new holes to be drilled.

The new engine was then removed and stowed on the flight deck where efforts to preserve and maintain it had to be accomplished. Once the new engine was removed, the drilling of new bolt holes could begin. The next step required the sizing and installation of the foundation pads to the gallery deck. Once installed they had to also be drilled and machined to allow a level plane for the engine to rest. The number of steps in this process leave the door open to allow many errors, as well as schedule delays to enter into the process.

PLANNING

The design and construction of the new engines are accomplished at the Naval Air Engineering Center (NAEC). After erection, they are sent to installing activities such as the Philadelphia Naval Shipyard. After meetings held with NAEC engineering and production personnel, they agreed to support the shipyard's effort by drilling the new engines to specifications to be provided by the shipyard. Concurrence by NAEC was received **31** August 1988.

The new arresting gear engines were scheduled to begin erection in September 1989. This meant that any useful information would be required by NAEC prior to that date. This required the data to be retrieved prior to the ship's arrival at the shipyard and therefore, prior to the removal of the existing engines from the ship. Photogrammetry became the method of choice for recovering this data based on accuracy requirements and ease of data extraction.

Pre-planning, as with most photogrammetric applications, was a significant part of the project. First, the ship's availability was considered and its home port of North Island, San Diego, Ca. was chosen by the shipyard to perform the photogrammetric survey. A June 1989 time frame was proposed, and ultimately accepted. To deal with the technical issues, the shipyard required the photogrammetric contractor to perform a feasibility study to determine not only the best photogrammetric approach but also to identify any technical issues that would have to be addressed prior to the photogrammetric survey team's arrival in San Diego. The method of photogrammetry (convergent or stereo) and requirements of said method needed to be determined. Because individual point coordinates were needed for bolt hole centers the convergent method of photogrammetry was ideal. The existing bolts extend through the gallery deck and are visible from the hanger bay. The overhead clearance of 7.62 m (25 feet) provides ample distance to provide good camera angles.

The basic photographic plan was the same for each of the four engines. Two athwartship rows of photographs each were to be taken from a 4.57 ❑ (15 foot) high rolling platform with the camera approximately 3.05 m (10 feet) below the gallery deck. To aid photographic viewing of the bolts, because of obstructing transverse stiffeners, both rows of photos were offset forward or aft of the engine above. Locations of photo stations within a row were pre-planned to avoid excessive obstruction by longitudinal stiffeners. As a result, each photograph was oblique rather than "straight on" insofar as viewing angle was concerned.

To assure strong inter-connectivity amongest all photos, a series of self adhesive stick-on targets were attached at pre-planned nominal locations along the stiffeners and extemporaneously at strategic locations on the underside of the gallery deck in the vicinity of bolt groups. Both types of target locations also served to allow tying in of auxiliary close up photos taken as needed in particularly obstructed situations; i.e. where a bolt(s) could not be seen by two or more photos from the main scheme of pre-planned camera stations. Finally, to assure that the laboratory-assembled series of photos spanning some 15.24 m (50 feet) would not be subject to scaling or "bending" errors, several very accurate 6 foot steel rules were clamped into the overhead, end-to-end, and aligned parallel to an adjacent taunt piano wire. Actually, small gaged gaps were left between the ends of the scales. These gaps were added into the calculation of known locations of targets previously placed on the scales.

The development of a suitable target for the bolt hole centers took on much more of a research and development effort. Since the engines existed, hence the mounting bolts existed, it was decided the center of existing bolts would be used to represent the center of the existing bolt holes. Ideas ranging from a threaded "nut like" target that could be screwed on to a magnetic type that could be stuck on were investigated. Since a majority of the bolts were installed from the hanger bay side of the 03 level (only the bolt head showing), and the need for an accurate depiction of the bolt's centers were paramount, the following idea was developed.

A three pronged fixture (target placement device) which fit over the hexagonal bolt head was used. In the center of the fixture was a "syringe" type device that allowed for a small white dot to be placed in the center of the bolt head. In order to be able to identify the bullseye, it was necessary to have the ship's force pre-paint all the bolt heads flat black.

The numbering sequence for all targets was developed in two phases. The first was a four digit system which gave each bolt on all four engines a unique number. The second was a five digit system which gave a unique number to each tie-in target used. This simple, yet unique, numbering sequence allowed an excess of 250 photographs to be taken without the possibility of disorder.

With the pre-planning completed, the actual retrieval of data from the work site began. The production work sequence allowed for this data collection to be completed over a two week time frame (**13** - 27 June 1989). Essentially, the first week was spent in preparation and the second in the actual photography segment. Site preparation included :

(1) installation of the tie-in targets;
(2) preparation of bolt heads to accept bullseye installation;
(3) installation of bullseye on bolt head ;
(4) installation of scales;
(5) numbering of all tie-in and bolt head targets;

The photography segment included:

(1) laying out and identifing camera stations;
(2) installation of the camera on a rolling staging assembly;
(3) taking of all photographs;
(4) preparation of darkroom;
(5) development of photos;
(6) intense review of all negatives;

The main scheme photos of each engine were taken with a WILD P31 photogrammetric camera employing glass plates as the negative recording medium (see Figure(l)). All photos were carefully reviewed near the job-site so as to ascertain which bolts were not captured on two or more photos. Numerous instances so identified owing to stiffeners, cables and lighting fixtures were then resolved by taking very close-in shots with a semi-metric Rolleiflex 6006 camera (Figure 2) employing 70mm Kodak Plus-X Estar-base film. Figures 3 and 4 are typical photos from the two cameras.

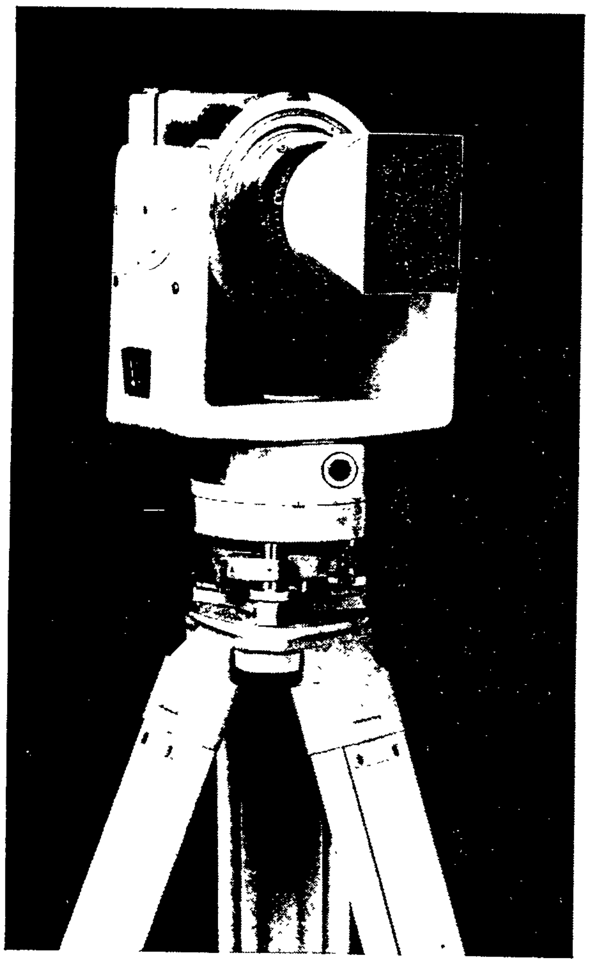

Fig. 1 Wild P31 photogrammetric camera

Fig. 2 Rolleiflex 6006 camera

Fig. 3 Typical photo from Wild P31 photogrammetric camera

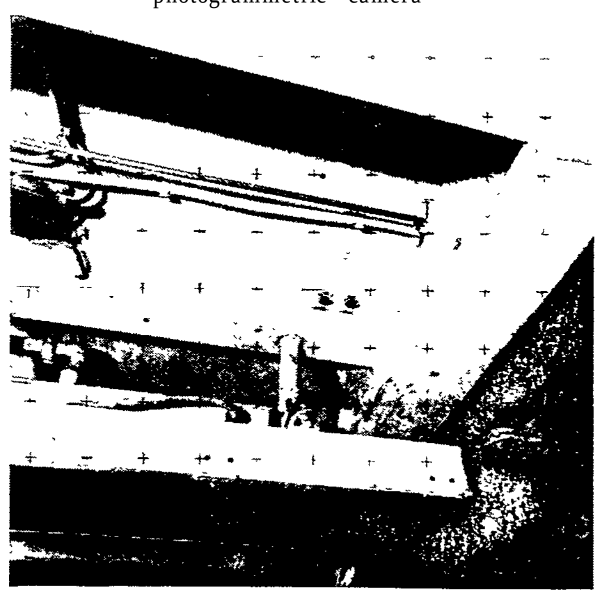

Fig. 4 Typical photo from Rolleiflex 6006 camera

RESULTS

In the time frame of July through August both the data reduction and data analysis were accomplished. The contractor reduced the data from the negatives and forwarded it to the shipyard in a pre-determined format. Data points which could not be captured, either by inability to set a target or take a photo, were identified. **10%** of the points were not captured photogrammetrically. The bulk of the non-captured points were not capable of being physically targetted. Coordinates for these points came from adjacent photogrammetric points and physical measurements taken on site.

With all points assigned a set of coordinates, an error analysis was performed to determine the total possible error between the actual center of the existing bolt hole and the identification of this location through photogrammetry.

In a worst case scenario the various possible errors would be from photogrammetry (.406 mm; .016 inch), placement of the bullseye (.787 mm; **031** inch), and actual location of existing bolt in the hole **(1.57 mm; .062** inch). It is therefore possible that the identified center of the existing hole by photogrammetry could be off by as much as 2.77 mm **(.109** inch). At the worst case. the accuracy-of locating the existing holes would allow for the installation of new bolts. However, when this theoretical error is added to the allowable drilling error (+ .787 mm; + .31 inch) of the new engine by NAEC there was a probability that some bolts would not fit.

In order to eliminate even this remote possibility, the shipyard entered into discussions with NAEC. Through technical precedence, analytical reasoning and prior knowledge of a potential problem, the shipyard was able to convince NAEC to enlarge the new bolt hole sizes from **23.81** mm **(15/16** inch) to 25.40 mm **(1** inch). This extra **1.57** mm **(1/16** inch) increased the probability that all bolts will fit.

Additional problems were that the existing engine which has six (6) rows of bolt holes (266 holes) while the new engine which only has four (4) rows of bolt holes (190 holes). With the accurate location of these additional 76 holes, the shipyard was able to convince NAEC to drill the extra holes in the engine. This will allow for all the existing bolt holes to be used and thus reduce expensive deck repairs.

Another phase of data analysis was to determine how many bolts would not fit if the new engine were drilled to the standard NAEC bolt hole drawing. An analysis to determine the acceptable limits of existing bolt hole locations verses standard drawing locations was completed. The results revealed that as many as 22% of the holes either in the deck or engine would require rework.

The final phase of this project was to develop drawings from the data and the delivery of these drawings to NAEC. There were eight drawings developed using the shipyard's computer aided design equipment, two drawings for each engine. One drawing showed existing bolt hole locations in the NAEC standard drawing format. The second was a recomputation of the data points (bolt hole locations) in order to simplify the drilling process at NAEC. The development of these drawings was completed for delivery to NAEC on 4 October **1989.**

CONCLUSION

The evolution of this project has run nearly 15 months from its inception in the summer of 1988 to the delivery of the drawings to NAEC 4 October 1989. Although the final conclusion will be sometime in the future (the installation of the new engines), some positive results can be noted at this time.

1. Data retrieval of complex nature can be accomplished at remote sites (i.e. outside PNSY).
2. Location of bolt holes can be found without disrupting existing conditions or ship's force routine.
3. Large quantities of data can be obtained and reduced in a relative short time frame.
4. The use of photogrammetry in this application can save an estimated 228 rework.
5. Concrete data obtained with photogrammetry convinced NAEC of the necessity to drill 25.40 mm **(1** inch) holes verses **23.81** mm **(15/16** inch) holes and to drill **266** holes verses **190** holes.
6. Data obtained prior to initiation of work at NAEC allowed correct holes to be pre-drilled in each engine in order to eliminate rework and schedule impacts during overhaul.

The success of this project has shown that photogrammetry can be employed to give not only accurate data but also data well in advance of a ship's arrival. This achieves a quality product while also allowing production worksites to open when necessary to balance production workloads.

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Paper presented at the NSRP 1990 Ship Production Symposium,
Plister Hotel, Milwaukee, Wisconsin, August 21-24, 1990

In Search of a Level Playing Field: The Shipbuilders Council of America and the Issue of Foreign Shipbuilding Subsidies

8A-1

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ABSTRACT

This paper discusses the origins of decision by the Shipbuilders Council of America to file a petition under section 301 of the Trade Act of 1974 charging Japan, South Korea, West Germany and Norway with unfair trade practices in shipbuilding and ship repair. The progress of negotiations between the U.S. Trade Representative and foreign governments is presented as are the actions of the Organization for Economic Cooperation and Development (OECD) to address the reduction of unfair subsidies. The paper provides insight into the future course of action of the U.S. Government as well as the Shipbuilders Council of America in their continuing effort to provide for the reentry of U.S. shipbuilders into the worldwide commercial shipbuilding and ship repair markets.

BACKGROUND

During much of the 1980s, traditional shipyards throughout the world suffered from the worst shipbuilding recession in history, precipitated by the oil crisis of the mid-1970s and its subsequent detrimental effect on seaborne trade. Figure 1 shows the world shipbuilding orderbook in gross tons from 1970 to 1990.

The severity of the situation reflected not only the cyclical nature of the shipbuilding business responding to fluctuations in the shipping market, but also the massive overbuilding of shipbuilding capacity that had been undertaken in Japan and Europe in response to an unprecedented, highly-speculative demand for new ships--particularly tankers--during the 1960s and the early 1970s. During a ten-year period, for example, Europe increased its shipbuilding capacity by 136 percent and Japan by 650 percent. Exacerbating the situation was the entry into the marketplace of new, government-supported yards such as South Korea employing cheap labor.

The response of most governments of the world in the 1980s to this situation was to provide increased measures of shipbuilding assistance. If the success of these measures can be defined as keeping merchant shipbuilding capability alive, then these governments achieved some degree of success. Only three governments responded to the crisis by terminating commercial shipbuilding subsidies. The United States was first in 1981.

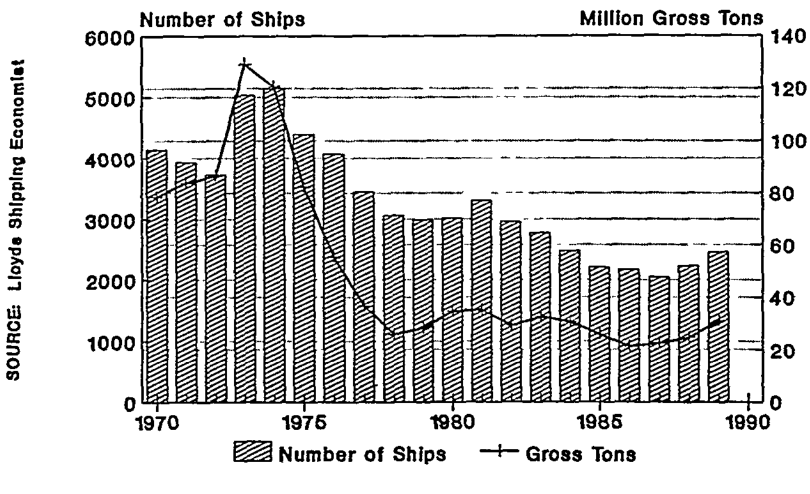

Figure 1. World Shipbuilding Orderbook.

followed later in the decade by Canada and Sweden. It is interesting to note that these three countries are also the only ones to suffer a complete collapse of commercial shipbuilding markets in the 1980s.

In the United States, all aid to domestic commercial shipbuilding, including the Construction-Differential Subsidy (CDS) program, was terminated. Forced to compete without government subsidies in a market dominated by government subsidies, American shipbuilders were unable to attract commercial customers. Until February 1990, when Matson Navigation ordered a containership from the San Diego-based National Steel and Shipbuilding Company (NASSCO). the last order for a large, oceangoing commercial ship placed with a U.S. yard was in 1984. Figure 2 shows the number of commercial ships on order at U.S. yards from 1970.

Lacking commercial customers, the U.S. shipbuilding industry turned to the U.S. Navy--and, to a lesser extent, the U.S. Coast Guard--for work in the 1980s. Government contracts alone, however, could not sustain the U.S. shipbuilding industrial base. The Shipbuilders Council of America (SCA) tracks shipyard closures from the baseline established by the Navy and the Maritime Administration's October 1982 Shipyard Mobilization Base of 110 shipyards, including both ship construction and ship repair facilities. By 1989, 46 shipyards had closed--a 42 percent decline--thereby putting the Shipyard Mobilization Base at 64 yards. Shipyard production worker employment in 1982 was 112,455. By 1989, that number had decreased to 76,282, representing a loss of 35,173 production workers, which is a 31 percent decline. Figure 3 shows the decline in the private U.S. shipyard base from 1982.

FACTORS IMPACTING SCA'S DECISION TO FILE PETITION

Decline in Navy Work Forecasted

During the early 1980s, the Navy's extensive rebuilding program sustained at least a portion of the nation's shipbuilding base, including those yards that normally would be considered commercial yards. Competition for Navy work was fierce, however, and, as the decade wore on, began to take its toll. At the same time, it was becoming clearer that the Navy workload would inevitably decline. Currently, the Shipbuilders Council predicts that the decline in FYs 1991 and 1992 will continue to be moderate, but that the remainder of the decade could well see

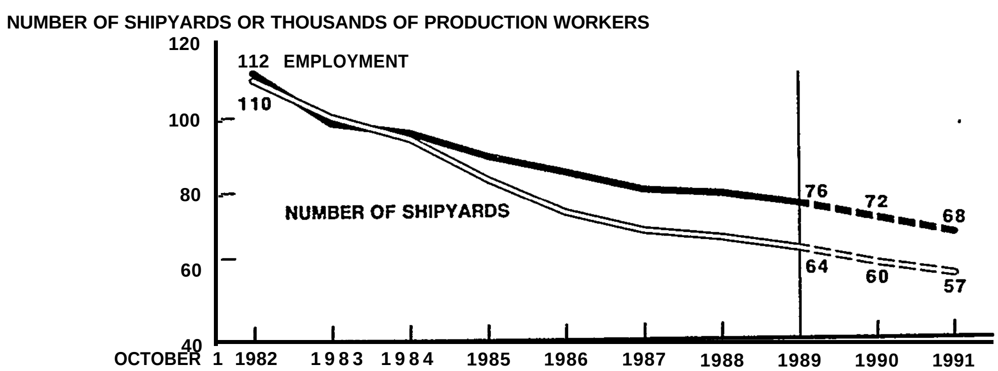

Figure 2. Private U.S. Shipyard Base.

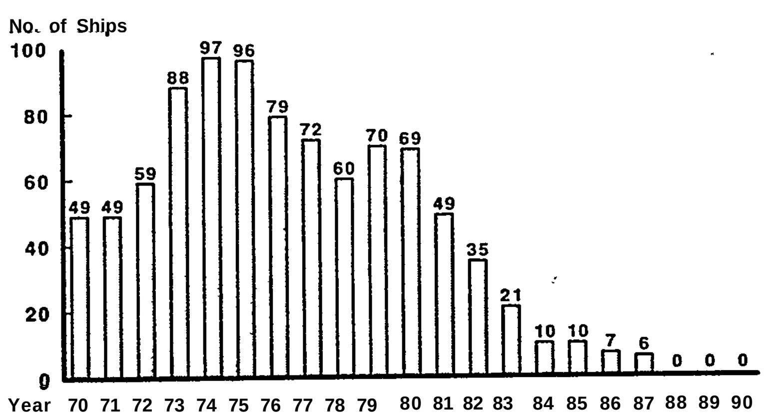

Figure 3. Commercial Ships on Order at U.S. Private Yards.

a much sharper decline, concomitant with decreases in the budget for naval ship construction. Consequently, U.S. shipbuilders cannot continue to count on Navy work.

Positive Changes in the Commercial Market

All of the shipbuilding forecasts during the past year and a half predict a significantly improved demand and increased prices for commercial ships in the 1990s. The primary reason for this optimism is the need for replacement ships. The world's merchant fleet is old: By 1992, more than 40 percent of the current fleet would be more than 20 years of age, and another 25 percent would be 15 to 19 years old.

Conditions in the commercial shipbuilding market are already improving. As of January 1, 1990, the number of commercial ships on order worldwide represented a 41 percent increase over the January 1, 1989 orderbook, and a 75 percent increase over two years ago. During the first quarter of 1990, there was even greater growth in the number of new ship orders. The shipyards of both Japan and South Korea have substantial backlogs. By the mid to late 1990s, deadweight tons (dwt) on order is expected to be at least double and as much as quadruple that of 1989.

Figure 4 shows the world orderbook for commercial ships to 1990 in millions of gross tons and a composite of orderbook forecasts from 1990 to 2000./1

Concurrent with the rise in new ship demand is the rise in ship prices. For example, five years ago, the average price of a medium-size very large crude carrier (VLCC) was around $44 million. Today, the price is more than double, and is still rising. Tight shipbuilding capacity is one important factor in continuing ship price escalation.

Subsidies Have Kent the U.S. out of Commercial Shipbuilding

With the anticipated decline in the Navy market, it is the commercial market that offers a long-term future for American yards. But the U.S. shipbuilding industry can only be a player in the international market if foreign shipbuilding subsidies are eliminated. The subsidization of commercial shipbuilding by foreign governments has effectively denied market access to American shipyards for nearly a decade. Not only have these subsidies been used to shore up shipbuilding industries and attract export customers, they have enabled the practice of producing ships at or below costs.

The impact of direct and indirect government subsidies on ship prices was summed up as follows by Drewry Shipbuilding Consultants in their November 1988 report, "World Shipbuilding Market; Prospects to 2000":/2

> "Directly, government assistance has led to reduced newbuilding prices by providing direct subsidies to individual

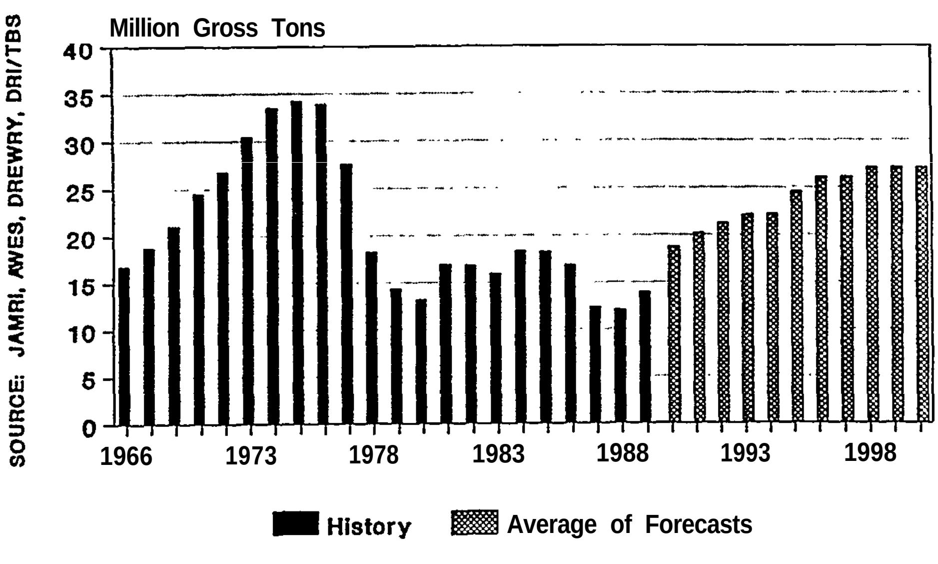

Figure 4. World Commercial Shipbuilding, History and Forecasts.

> contracts and by providing an environment which allows yards to make available cheap finance. Indirectly, governments have allowed yards to run up substantial losses on newbuildings operations and have underwritten such losses."

In his presentation at the Shipbuilders Council of America's Marketing Seminar in January 1990/3, Dr. Martin Stopford, Senior Shipping Economist at the Chase Manhattan Bank in London, explained that through subsidies governments prolonged shipbuilding overcapacity problems and depressed ship prices. He said that they did this partly for political reasons, partly in response to South Korea's shipbuilding expansion, and partly because they failed to understand the severity of the crisis. According to Dr. Stopford:

> "Instead of tackling the capacity reduction with a single clean cut, most shipbuilders tackled restructuring as a series of steps down, interspersed with periods of consolidation, during which each shipyard sought to maintain its market share at the expense of others by means of price cutting backed by subsidy."

At a conference in Genoa, Italy, in November 1989, Werner Fante, Director of the Association of West European Shipbuilders Association (AWES) also addressed the phenomenon of unprofitable pricing policies followed by shipbuilders during the 1980s:/4

> "Officially, it was pretended that low prices were based on high efficiency and losses were explained as the deplorable results of variations in exchange rates, higher material costs, and unforeseen burdens of ship financing. In a very few cases, the failure of wrong market strategies and fixing of prices without making provision for technical and commercial risks were admitted."

During this time, the U.S. Government unwittingly encouraged and supported shipbuilding subsidization by foreign governments in a variety of ways, while at the same time it demanded that U.S. shipbuilders "go it alone" in the international market. One of the U.S. Government's actions that was post damaging to American shipbuilders was the Section 615 amendment to the 1936 Merchant Marine Act. This special legislation allowed U.S.-flag operators receiving Operating-Differential Subsidy (ODS) payments from the U.S. government to buy from subsidized foreign yards during a temporary one-year "window" that subsequently was stretched to five years.

Of the 33 new ships built in foreign shipyards under the Section 615 amendment, all but three were built in the three countries that most heavily distorted the shipbuilding marketplace during the 1980s: South Korea, Japan, and West Germany. As one example, West German federal and regional governments contributed nearly $165 million to have two of its shipyards build five U.S.-flag containerships for American President Lines, which so far has received approximately $19 million from the U.S. Government to operate them. /5,6

Thus, the U.S. Government, through Section 615 legislation, encouraged one of its own subsidized industries to take advantage of a market distorted by the actions of foreign governments. It put our government in the position of rewarding the subsidy practices of our trading partners at the expense of our own country's shipbuilding industry.

Types of Subsidies

SCA's decision to file a Section 301 petition requesting the United States Trade Representative (USTR) to take action to terminate foreign shipbuilding subsidies followed its own preliminary investigation of the extent of these subsidies. The results of this investigation were published in October 1988 as a study of the subsidy programs of the then top-ten ship producing countries in the free world./7' The information contained in that study has subsequently been refined and expanded as more data has become available. In general, the major types of shipbuilding subsidies that have been and are still being provided are the following:

Special Financing (Credits). This category includes government-subsidies related to the financing of ship purchases for export or domestic customers and can include loans from government banks as well as interest subsidies and/or loan guarantees from federal and regional governments.

Construction Subsidv Grants. This type of subsidy encompasses direct government payments to shipyards for building ships, amounting to a certain percentage of the contract price. The Sixth Directive of the European Community, for example, specifically allows this type of subsidy and sets a limit on the percentage of the contract price that can be paid. This limit was 28 percent in 1988, 26 percent in 1989, and 20 percent in 1990. The limit, however, does not apply to contracts

with shipowners from those nations that are defined as less-developed countries (LDCs).

Shipyard Reorganization Aid. After a long period of hesitation, the EC and Japan finally began to recognize that they had overbuilt shipbuilding facilities in response to speculative ordering, and that they would have to take steps to reduce excess capacity. To ease the pain of restructuring, government-provided shipyard reorganization aid was instituted in Japan and the EC. This category covers a wide range of government subsidies to help shipyards modernize their facilities or to otherwise adjust to downsizing, and has included capital infusions, loan subsidies and guarantees, government buy-ups of redundant or outmoded facilities, and special tax benefits.

At times, the distinction has been blurred between reorganization aid for the purpose of shipyard rationalization and Shipyard Investment Aid--i.e., funding from governments to help shipyards build better shipbuilding plants and improve production techniques or to bail them out of financial difficulties.

Research and Development Aid. This type of aid involves government funding of research and development programs related to ship and/or ship production technology.

Tax Benefits. This category encompasses governmental tax measures to shipowners and/or shipbuilders that are not generally available to all other industries within that country. It includes tax reductions or tax exemptions to shipowners, such as special depreciation for ships and depreciation write-offs before the ship is delivered; and special tax provisions for shipyards, such as tax reductions on capital investments and exemptions from import taxes on materials.

The Omnibus Trade Act of 1988

In August 1988, awareness of the significant decline of the U.S. industrial base, coupled with the growing trade imbalance between the U.S. and its trading partners, precipitated stronger legislation to encourage foreign countries to accept American exports and to provide for retaliatory measures against countries that engage in unfair trade practices. Heartened by the legislation--which amends the 1974 Trade Act and was passed by overwhelming margins in both the House and the Senate--the Shipbuilders Council of America, as the trade association of the country's major shipbuilders, began to explore the options available to the U.S. shipbuilding industry under the new law.

Because the Tariff Schedules of the United States as well as judicial precedent have determined that ships are not "merchandise" or "articles" of import, it was concluded that Section 301, as strengthened in the Omnibus Trade Act of 1988 represented the most fruitful avenue for U.S. shipbuilders to pursue. Section 301 provides for U.S. Government action to respond to unfair trading practices. Among other things, the amendments of the 1988 Trade Act specified additional practices actionable under the Act, shortened the time limits for responding to a petition, transferred section 301 authority from the President to the United States Trade Representative (USTR), and provided a new mandatory retaliation requirement in cases involving violations of trade agreements or other "unjustifiable" practices.

The decision of the SCA to file a 301 petition was in line with the objectives of the Shipyard Recovery Program, the SCA-developed plan to restore the competitiveness of the U.S. shipbuilding industry in the commercial market. The Shipyard Recovery Program recognized that U.S. Government action to end worldwide shipbuilding subsidy practices was critical to dissolving the market distortions created by government subsidies.

THE 301 PETITION

Filing the Petition

The SCA hired the law firm of Collier, Shannon & Scott to prepare its Section 301 petition, which it filed with the Office of the U.S. Trade Representative on June 8, 1989./[8] The petition requested the USTR to take action to eliminate subsidies to foreign shipbuilding and repair industries and documented specific policies and practices of four countries. Under the terms of the Trade Act, the USTR had 45 days in which to weigh the petition's merits and to decide whether or not to initiate an investigation of the petition's allegations. The petition was examined by an interagency review group, comprised of representatives from various government agencies, including the Departments of State, Commerce, Justice, Transportation, Defense, Labor, Treasury, the Office of Management and Budget, the Council of Economic Advisers, and the U.S. Trade Representative.

Before and after filing the petition, the SCA worked to garner

political support for it on Capitol Hill. Ultimately, the petition received the support of 280 members of Congress --230 representatives and 50 senators--who signed letters urging the USTR to begin negotiations to eliminate foreign shipyard subsidies.

Countries Targeted in SCA Petition

The SCA's Section 301 Petition targeted the shipbuilding and repair subsidies in four countries: South Korea, Japan, West Germany, and Norway. Although all of the major shipbuilding nations engage in unfair subsidy practices, the Shipbuilders Council focused on these four because they have the most blatant subsidies which have caused the shipbuilding industry in the U.S. the most harm, and because together they accounted for over 55 percent of the world's commercial tonnage on order at the time of the filing. (At the end of 1989 the percentage had grown to 60 percent.) Table I compares the major kinds of shipbuilding aid programs in these countries against those of the United States. Table II shows the estimated amounts of shipbuilding aid budgeted in Japan and West Germany for 1987 and 1988, as compared with the United States. A narrative summary of the programs in each of the countries named in the petition, along with subsidy actions subsequent to the petition filing, follows:

South Korea. The South Korean government, largely through the state-owned Korea Development Bank, underwrote shipbuilding programs from their inception, allowing South Korea yards to pile up enormous debts while under-cutting ship prices worldwide. At the time of the filing of SCA's petition, the debt of the four major South Korean

Table I
SHIPBUILDING AID IN 301-TARGETED NATIONS COMPARED WITH UNITED STATES

Countrv	Shipowner Special Financing.	Construction Subsidies	Yard Reorg. Aid; Investment Aid	Ship R&D Funding	Tax Benefits
JAPAN	Yes ***	unknown	Yes ***	Yes **	Yes
S.KOREA	Yes	unknown	Yes ***	unknown	Yes
WEST GERMANY	Yes	Yes ***	Yes ***	Yes	Yes
NORWAY	Yes ***	unknown	Yes	Yes	Yes
UNITED STATES	NO	NO	NO	Limited	Limited

Keyed where known: *** Very Significant, ** Significant, * Some

Table II
COMPARATIVE SHIPBUILDING SUBSIDIES BY COUNTRY
($ in Millions)

	UNITED STATES		W. GERMANY		JAPAN	
	1987	1988	1987	1988	1987	1988
Special Financing, Export Ships	0	0	197.6	139.8	138.3	210.6
Construction Subsidies	0	0	230.7	414.7	.1	0
Investment Aid	0	0	62.5	21.5	22.9	29.5
Restructuring Aid	0	0	7.0	106.1	562,6	4.1
Other Indirect Aid	1.4	.3	70.9	141.7	484.1	327.6
	$1.4	.3	8568.7	823.8	$1208.0	571.8

yards, equivalent to four times their equity capital, was $4 billion.

Subsequent to the petition filing, the South Korean government approved a rescue package for Daewoo and two other yards consisting of interest-free loans, debt moratoriums, tax exemptions, and other benefits, for Daewoo shipbuilders, the Korea Shipbuilding & Engineering Company (KSEC) and Inchon Shipbuilding Company. By far the biggest recipient of the government's largess was Daewoo. Repayment of Won250 billion ($372.7 million) of its Wonl.4 trillion ($2.1 billion) debt was put off for seven years, and the yard was given a new loan of Won150 billion ($223.6 million). The South Korean government also has ship finance programs.

Japan. Since 1978, the Japanese government has helped its shipbuilders to reduce their massive overcapacity, the buildup of which the government had encouraged in the first place. In return for a commitment by the industry to down- size, the government allowed the industry to form a cartel and provided financial aid and loan guarantees associated with the mothballing of facilities, as well as other subsidies, which allowed the yards to operate in the red for a number of years. Now that the market has vastly improved, shipbuilders are modernizing and reopening their mothballed facilities.

The Japanese government has always been heavily involved in ship and shipbuilding-related research and development. In JFY 1989 the Government adopted a new program described by the Director-General of the Maritime Technology and Safety Bureau, Ministry of Transport (MOT), as "a system to encourage technical development efforts to materialize such sophisticated ships which could well meet the needs of the next generation."/9 Projects include development of 3 five-year fast cargo ship project called Techo-Superliner 93 and a high reliability diesel engine for ships.

The Japanese government also provides partial funding for export ships through the Export-Import Bank, and for domestic ships (particularly high-technology ships) through the Japan Development Bank. Regarding domestic ship financing, subsequent to the SCA's 301 filing, the MOT announced that its JFY 1990 budget request was Yen66.4 billion (about $458 million), which was considerably higher than the JFY 1989 budget./1O

West Germany. Both federal and regional governments subsidize commercial shipbuilding in West Germany through direct cash infusions, ship production grants, preferential financing, and credit guarantees. On the federal level, money for shipbuilding subsidies has been paid out of budgets for defense and for economic assistance to developing countries, as well as from funds for direct shipbuilding assistance. Regarding the latter, subsequent to SCA's filing of the 301 petition, the German government announced that it would add Dm300 million ($101.7) more to its ship production aid program for FY 1990, bringing this year's allotment to Dm343 million ($174.4 million)./11

Two shipbuilding groups have particularly benefitted from government subsidies: state-owned Howaldtswerke Deutsche-Werft (HDW) and partially government-owned Bremer Vulkan. Most of the ships on order at the HDW yard in 1987, 1988, and 1989 received some government subsidy, with the level of aid particularly high in 1987 and 1988. Two of the contracts were especially controversial, although they ultimately received approval from the EC Commission: the previously-mentioned American President Lines (APL) containership deal and Zim Israel containership deal. Of the subsidies paid for the APL ships (three built at HDW and two at Bremer Vulkan), Dm125 million ($69.4 million) came out of funds from the German Ministry of Defense despite the fact that the vessels are merchant ships and cannot contribute to the NATO sealift pool since they are operating in the Pacific and cannot transit the Panama Canal. The U.S. Government contributed to this process by waiving research and development costs on the German purchase of HARPOON.

In the Zim Israel case, the West German government termed Israel a "lesser-developed country" so that it could bypass EC rules and pay a 25.4 percent on an estimated $100 million contract to build four containerships. (Originally, two of the ships were to be built at the Bremer Vulkan yard, but the entire order was transferred to HDW.) In 1989, the German government provided Zim Israel with another low-credit package and a 30 percent subsidy so that HDW could build three more ships.

Information on German R&D programs has been difficult to come by. It was not known until after the filing of the 301 petition, for example, that the Federal Ministry of Research and Technology (BMFT) and the Federal Ministry of Economics are subsidizing R&D in computer-controlled ship production techniques.

Norway. The government of Norway

provides domestic and foreign shipowners with a variety of attractive financing programs for the purchase of ships, fishing vessels, and equipment. One program, for example, offers interest rates as low as two percent. Another program makes loans available at four percent, with 12 years to repay, including a three-year grace period.

THE GOVERNMENT'S RESPONSE

USTR's Request to Withdraw Petition

On July 21, 1989, the Shipbuilders Council of America and the United States Trade Representative announced that they had reached an agreement: The SCA would withdraw its petition temporarily to allow the USTR a period of time in which to pursue the termination of shipbuilding subsidies through traditional negotiating channels before using the more confrontational remedies provided under Section 301 of the Trade Act.

In a formal statement, USTR Carla Hills acknowledged that foreign government subsidization of ship construction and repair was a "serious problem." She announced that the countries named in, SCA's 301 petition had declared their willingness to negotiate [with West Germany represented only through the European Community (EC)], and that she intended to engage in talks with these countries, primarily through the mechanisms of the Organization for Economic Cooperation and Development (OECD) and the Uruguay Round of the General Agreement on Tariffs and Trade (GATT). Ambassador Hills promised that if insufficient progress was not made in these negotiations by March 31, 1990, then the SCA would be invited to resubmit its petition.

N e g o t i a t i o n s six

Immediately after the agreement was reached between the USTR and the SCA, a U.S. Trade Policy Review Group (TPRG) began devising a strategy for negotiating a multilateral agreement to discipline shipbuilding subsidies. The U.S. State Department had already talked with officials at the OECD's shipbuilding group, Working Party Six, and had applied for full membership in June 1989, thus paving the way to use that body as a forum for subsidy talks. (Other members of Working Party Six are Japan, Germany, Norway, Finland, Great Britain, France, Ireland, Denmark, the Netherlands, Sweden, Belgium, Italy, and Spain. South Korea, which is not an OECD member, is represented through a special liaison group.) In addition, Working Party Six already had on the books an agreement to remove shipbuilding subsidies that could be used as a framework.

<u>The RGA.</u> The "Revised General Arrangement (RGA) for the Progressive Removal of Obstacles to Normal Competitive Conditions in the Shipbuilding Industry," was adopted by the OECD Council on Feb. 23, 1983. Signed by 14 nations plus an EC representative, the RGA committed the signatories to refrain from increasing aid or adding new shipbuilding subsidies, and to gradually eliminate existing subsidies. That commitment, however, was largely ignored. In general, shipbuilding aid in the countries participating in the agreement was not reduced; moreover, in many of the countries, the level of aid was increased and new shipbuilding subsidy programs instituted.

Among the "obstacles to normal competitive conditions in the shipbuilding industry" the RGA signatories pledged to reduce were:

a) Government-subsidized export credits;
b) Direct subsidies to the shipbuilding industry;
c) Customs tariffs or any other import barrier;
d) Discriminatory tax policies;
e) Discriminatory official regulations or internal practices;
f) Specific aid for investments;
g) Subsidies for restructuring of the domestic shipbuilding industry;
h) All other forms of indirect public aid which are obstacles to normal competitive conditions in the shipbuilding industry.

<u>The U.S. Proposal.</u> On October 16, 1989, the U.S. delegation brought to the Working Party Six negotiating table its proposal to accelerate implementation of the RGA. Under the terms of the proposed agreement, participating governments would be required to refrain immediately from implementing new or increased measures of shipbuilding assistance and to develop individual timetables for eliminating existing shipbuilding subsidies, with final termination by the end of 1991. The proposal included a provision calling for the development of a mechanism to enforce the agreement.

The U.S. proposal also attempted to more clearly define the types of shipbuilding subsidies encompassed by the general categories stated in the RGA. Tied aid (mixed foreign aid and supplier credits used to sell ships to developing countries) and government ownership of merchant shipyards were added to the list of market distorting practices to be eliminated.

Although there were objections to

different parts of the U.S. proposal from the individual member-nations of Working Party Six, the overall response was to "agree in principle" to eliminate shipbuilding subsidies and to continue negotiations. Various drafts of proposals and counter-proposals were presented over the next five months. The U.S. negotiating team eliminated tied aid from its proposal and added language to exempt purely domestic programs from the scope of measures of assistance to be eliminated. Tied aid was to be taken up in other negotiations involving the U.S. Treasury Department.

PROGRESS TO DATE

The Current Draft Document

General Description. As of this writing, the format of the draft document consists of the subsidy convention--which basically describes the purpose and scope of the agreement. More importantly, it establishes mechanisms to monitor, verify, and enforce the provisions of the agreement. Annex I identifies the subsidies to be prohibited. Annex 2 sets the timetable for implementation of the agreement, and Annex 3 contains 3 list of programs that would be exempted from coverage under the subsidy convention. Each country has proposed a program that would be included in Annex III, which at the time of this writing had not yet been prepared.

Annex I. The following are the types of shipbuilding and repair subsidies that are under negotiation for termination (keep in mind that the preparation date of this paper is considerably earlier than the date of its presentation, and that the draft agreement may have changed by August):

a) Officially-supported export credits at terms more favorable than those of the OECD Understanding on Export Credits for Ships; i.e., 80 percent loans over 8½ years at 8 percent interest. In other words, this subsidy will continue as currently allowed. However, it appears that sometime in the future ship export credits will be shifted out of Working Party Six and into the OECD's Export Credit group. When that happens, ships will be subject to the same export credit provisions allowed within the OECD for other industries; namely. government-supported financing at the commercial interest reference rate (CIRR) in each country.

b) Direct official support for the operations of the commercial shipbuilding and repair industry, such as grants, below-market loans and loan guarantees, debt forgiveness, equity infusions, and the provision of other preferential goods and services.

c) Direct official support for investment in the commercial shipbuilding and repair industry, including the categories of aid mentioned above under operational aid, plus aid for research and development and restructuring Support. What constitutes acceptable R&D support is still under negotiation. Acceptable restructuring support would include measures tied to permanent closings of shipbuilding capacity and/or aid linked to the social effects of closures, such as problems associated with worker displacements.

d) Customs tariffs. This item is still under negotiation.

e) Tax policies and practices favoring the shipbuilding and repair industry. Exceptions still need to be spelled out.

f) Official regulations and practices and import barriers other than tariffs for new-built ships. The scope of this item still has to be determined.

g) Other forms of indirect support to yard activities. Agreement on the scope of this item has not yet been reached.

h) Publicly-owned shipyards. The survival of this item as a prohibited measure is doubtful, although the U.S., Japan and South Korea are pushing the EEC to adopt the provision.

j) Private practices. This item is under negotiation.

The European Commission, which is negotiating on behalf of the member nations of the European Community, has introduced an anti-dumping proposal which, when and if it is accepted, probably would be incorporated into this annex. The purpose of the proposal is to discourage builders from selling ships at "unfair" prices; meaning prices insufficient to cover the full cost of production plus a reasonable margin of profit. The U.S. endorses such a proposal.

Annex II, This section deals with the time period for phasing out the shipbuilding subsidies proscribed in Annex I. Current proposals range from immediate to five full years for ter-

mination of some measures of government support. The U.S. proposal says that it would require two years to repeal whatever statutes are on U.S. books that relate to shipbuilding support.

Missed Deadlines. The U.S. negotiating team pressed for a signed document by March 31, 1990, the deadline promised U.S. shipbuilders by USTR Carla Hills. When the date was not met, the SCA expressed "extreme disappointment" that the signatory nations had not been able to agree on a text outlining the practices to be outlawed and the details of the mechanism by which the countries would monitor, verify, and enforce the agreement.

Nevertheless, SCA felt that significant progress had been achieved, and, in consultation with the USTR, decided to defer refiling a 301 petition in order to allow the Administration more time. The SCA was hopeful that an agreement would be achieved by May 31, 1990, in time for the OECD Ministerial Conference, as was originally intended when the negotiating schedule was set in the summer of 1989. However, this was not to be. The U.S. trade negotiators returned from the May 5 and 6 OECD Working Party No. Six meeting in Paris without a signed agreement and extremely frustrated by their lack of success. Interestingly, the fact that subsidies for American shipbuilders were cut off over eight years ago has made the position of the U.S. negotiators more difficult. They have very little leverage in the talks because the unsubsidized U.S. shipbuilding industry has nothing of trade-off value to give up.

WHAT'S NEXT?

At this point, the U.S. team is prepared to keep on with the negotiations. The team feels that enough progress has been made to allow the process to continue. The next negotiations among the full working party are scheduled for June 18, 1990. Among the issues that need to be ironed out: the subsidy definitions in Annex 1 still need clarification; the minimum vessel size to which the subsidy prohibitions apply; what current programs will be exempt from the agreement (grandfathered); the time frame for the subsidies' phaseout; and how to set up the remedy process.

The SCA's concern is that the negotiations could continue to drag on interminably. Time is of the essence to U.S. shipbuilders, since they will continue to be denied access to the commercial market as long as foreign shipbuilding subsidies remain in place. The tenacity of the U.S. trade team might indeed result in an eventual victory, but it will be a hollow victory if it comes too late for U.S. yards.

It is already clear that the goal of the U.S. proposal to have all shipbuilding subsidies terminated by the end of 1991 will not be accomplished. If there is no resolution of the outstanding issues during the June Working Party Six meetings, then the negotiations are likely to slow down until the spring of 1991, since by fall the U.S. trade team will be heavily involved in the concluding sessions of the Uruguay Round of GATT (General Agreement on Tariffs and Trade) negotiations.

Even under the most optimistic scenario, which assumes that agreement is reached between the parties at the June Working Party Six meetings, shipbuilding aid could not be eliminated until the end of 1992. This means that for at least the next two years, the U.S. industry-- as the only unsubsidized shipbuilders in 'the world actively represented in Working Party Six--will not be able to benefit from the commercial shipbuilding boom of the 1990s as the subsidized shipyards of the world consolidate their market position.

An option currently under consideration by the SCA is to refile its 301 trade complaint, perhaps widening the scope of the petition to include those countries within the EEC that have been the most obstructionist in the negotiations. But whether remedies are pursued under Section 301 of the U.S. Trade Act, through the OECD, or through some other mechanism, it is clear that effective action can only come from the government level. In the last analysis, the achievement of a level playing field--and the survival of the U.S. shipbuilding industry--will depend on the willingness of the U.S. government to do whatever it takes to get foreign governments to stop the practices that are distorting the international shipbuilding market and to do it before market demand disappears.

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
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Paper presented at the NSRP 1990 Ship Production Symposium,
Plister Hotel, Milwaukee, Wisconsin, August 21-24, 1990

The Path to U.S. Shipbuilding Excellence-Remaking the U.S. into a World Class Competitive Shipbuilding Nation

8A-2

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ABSTRACT

U.S. shipbuilding has a unique opportunity now to reenter and compete profitably in world commercial shipbuilding. World shipbuilding demand is expanding rapidly and U.S. costs of most factors or inputs of production are today comparable to those of major shipbuilding countries. A path for regaining a U.S. commercial shipbuilding competitiveness is described and formal steps suggested which will be necessary to remake the U.S. into a world class shipbuilding nation.

Many of the proposed steps will be painful, but similar steps have been taken by other U.S. industries, such as manufacturers of automobiles, steel, construction, electronics, and appliances. They are deemed necessary if U.S. shipbuilding is to survive as a viable industry under conditions of declining defense budgets, consistent federal budget deficits, and increasing importance of trade to the U.S. economy.

INTRODUCTION

While the U.S. flag fleet maintained its size in both absolute (tonnage) and relative terms (as a percent of world fleet size) at about 17 million GRT (25.2 million DWT) or about 4.9% of world total in 1989, over 25% of that tonnage and 285 out of 681 ships in the U.S. flag fleet are "inactive" and generally obsolete vessels.

out of 390 privately owned vessels with a tonnage of 18.645 m DWT, only 167 (with 7.06 m DWT) serve foreign trade. The average age of the active U.S. flag fleet is in excess of 16.45 years, with a foreign going fleet age average of 11.4 years and a domestic fleet age average in excess of 19.2 years. The average age of "inactive" ships is estimated to be in excess of 28.8 years. The U.S. merchant fleet therefore competes with fleets of countries like Turkey, Thailand, and the Philippines for laurels of oldest fleet of merchant ships.

STATUS OF U.S. SHIPBUILDING

The volume of U.S. commercial shipbuilding as a percentage of world shipbuilding output in GRT has fallen from 8.4% in 1974 to zero percent in 1988 and 1989, as shown in Table 1. This trend will continue at least to 1991, after which at least one containership will be delivered. The major hope for the industry is now the required rebuilding (or life extension) of the U.S. cabotage fleet, which is now larger than the U.S. flag foreign going fleet in both numbers of vessels and GRT.

Table 1 - Volumes of Newbuilding Orders Accepted and Order Book at American Shipyards (100 GT and above)

Year	Orders Accepted 1,000 GT	%	Shipyard Order Book (End March) 1,000 GT	%
1970	543	1.9		
1971	871	2.9		
1972	1,316*	4.4	2,149	2.6
1973	2,131*	2.9	3,104	3.1
1974	2,122*	8.4	4,533	3.4
1975	4.8		5,383	4.7
1976	647	4.9	4,897	6.5
1977	137	1.2	4,640	9.0
197[illegible]	377 455	4.6	[illegible]	9.9
1980	714	3.7	1,578	5.1
1981	210	1.2	1,700	4.8
198[illegible]	[illegible]	1.[illegible]	[illegible]	2.4
1984	274	1.8	379	1.2
1985	20	0.2	516	1.7
1986	2	2×10^{-4}	316	1.3
1987	4	3×10^{-4}	189	0.9
1988	0	0	24	0.1
1989	0	0	0	0

* Increased sharply due to strengthened Construction Differential Subsidy (CDS).

Note: Percentage figures (%) indicate the share of world total.

Source: Lloyd's statistics.

U.S. flag shipping firms continue to aggressively order in foreign shipyards. During the period` 1986-1987, three U.S. flag operators (American president Lines (APL) . - since defunct), and Lykes ordered 30 containerships with a combined value of $1.381 billion.

U.S. owners (U.S. and FOC registry) ordered a total of 59 vessels in foreign yards between January 1987 and December 1989, with a tonnage of over 4.3 million DWT. These orders constituted 11.7%, 6.5%, and 4.4% of the world orders placed in these three years. U.S. owners therefore proved astute in replacing tonnage in 1986 and 1987, when newbuilding prices were comparatively low, at a rate nearly 60% above their proportional ownership of average tonnage. As a result, many U.S. owners are expected to benefit from lower financial costs of their fleets for years to come.

Considering commercial newbuildings completed (100 GRT plus), U.S. shipbuilding output reached a peak of 1.352 m GRT in 1979 which, at that time, constituted 9.5% of world output. Since then U.S. commercial shipbuilding output has plummeted to near zero. At the same time newbuilding orders for naval vessels increased from 6, with a value of $758 m in 1970, to 32 with a value of $9.886 m in 1988, as shown in Table 2.

Table 2 - Amounts of Newbuilding Orders for Navy Warships Contracted by American Shipyards (Unit: US$ million)

Year	Number of Vessels	Amount
1970	6	758
1975	16	1,677
1980	28	1,934
1981		2,842
1982	28	7,777
1983	27	5,041
1984	11	2,849
1985	11	1,679
1986	16	3,035
1987		3,522
1988	32	9,886

The actual number of deliveries of vessels by U.S. shipbuilders is shown in Table 3, which also indicates the gradual decline of shipbuilding revenues.

Shipbuilding employment in the U.S. on the other hand increased between 1976 and 1981 from 166,300 total (132,100 production sector) to 178,900 total (142,200 production sector) or by about 7%. It has since fallen by 111,000 and 82,500 respectively in 1988 or by nearly 33%.

During the same period (1976-1988) Japanese Western European shipbuilding employment fell by 78% and 71% respectively, while output in GRT fell by 55% and 61% during the same periods. At the same time, the average ship constructed has become significantly more complex and expensive. In value added terms Japanese shipyards increased their contribution per manhour three fold, versus a European increase which doubled value added between 1976 and 1988. Such measures of productivity are rather tenuous and are difficult to apply, particularly when shipyards produce different outputs and operate under different client imposed conditions.

Table 3 - Number of Deliveries by U.S. Shipyards

		Number Of Ships		
Year	Revenues ($ Million)	Merchant ships of 100 GT and above	Warships of 1,000 tons and above	USCG & Others
1983	9.49	12	80	12
1984	9.64	13		9
1985	9.48	8	76	9
1986	8.91	9		7
1987	8.72	1	77	5
1988	8.75	0	86	3
1989 •	8.66	0	[illegible]	[illegible]

• Estimated.

Note: Public-owned shipyards not included.
Source: MARAD

SHIPBUILDING COSTS

While the U.S. used to have the highest shipbuilding worker costs, this is no longer true. As shown in Table 4, U.S. shipbuilding wages are now lower than those of major shipbuilding countries such as Japan, West Germany, Finland, Holland, Norway, Denmark, and Italy, and about equal to those of France.

Table 4 - Trends in Comparative Wages of Shipbuilding Workers (Unit: US$/H)

country	1977	1980	1988	1989.
U.S.	8.08	11.94	14.82	15.64
Japan	5.11	6.77	14.59	15.82
West Germany	8.88	14.25	20.82	21.94
U.K.	3.64	7.58	9.91	10.90
Netherlands	8.63	12.69		15.92
Finland		–	15.95	17.04
Sweden	9.76	13.22		
Norway	9.20	11.97	19.96	21.80
Denmark	8.01	11.33	16.99	17.85
France	6.44	10.73	14.51	15.48
Italy	5.55	9.10	14.59	15.64
Spain	4.41	7.13		8.80
Taiwan	0.91	1.86	4.38	5.64
South Korea	1.40	1.72	4.31	5.98

• Author's personal inquiry.

Source: The U.S. Shipbuilding Industry', by C. H. Whitehurst, excepting the figures for 1988 taken from ISL's Shipping Statistics'.

British and Spanish wage costs are still significantlv lower. Taiwanese and Korean wage-costs are now about 38% of U.S. costs, up from 22.8% in 1982, and rapidly gaining as wages in those countries are escalating at nearly 20% per year now.

Material and service costs differ quite significantlv among shipyards; both within the U.S. and among U.S. and foreign shipyards in general. For example, U.S. Gulf Coast yards usually experience a 6% cost advantage in material and service costs over U.S. Atlantic and Pacific Coast yards. International shipbuilding material cost differences are much larger. Much of the cost differentials appear to be more a function of methods and procedures used in procurement than base material (such as steel) costs in different shipbuilding countries.

Shipbuilding steel prices, for example, differ bv onlv 6% for the same-quality and Quantity purchases of different shipbuilding steel plate and by less than 11% for shapes among various steel producing shipbuilding countries, such as the U.S., Spain, West Germany, Japan, and Korea. Similarly, shipbuilding outfit equipment, machinery, and material cost differences are comparatively small among the above mentioned countries.

Wages presented in Table 4 only represent a part of total labor costs which also include:

1. social benefit - such as health, pension, etc.;
2. training;
   bonus for profit sharing;
3 vacation; and,
5. relocation and hiring/firing.

While U.S. shipyards spend significantly more on social benefits (mainly health) and relocation, hiring/firing, and related costs, the Japanese builders, most Japanese yards have bonuses and more extensive training costs. Non-direct wage costs in the U.S. are about 38% of direct wage costs, while they average well over 56% for Japanese yards. (This number is subject to fluctuations as bonuses vary from year to year.)

In general, we found that the cost of the principal factor inputs, such as labor, steel, equipment, outfit materials, machinery, etc., have little significant variation among Western European, Japanese, and U.S. shipbuilding, with higher total wage or labor costs often balanced by lower material input costs. A recent study for a foreign shipbuilder actually indicates that, with similar expenditures in production manhours and overhead, most commercial vessels could be competitively built in the U.S. (In fact, at a cost about 5% below the cost of an equivalent vessel built in a typical Japanese yard.)

U.S. SHIPBUILDING TECHNOLOGY

Since 1970 all major U.S. shipyards have been extensively rebuilt and/or reequipped. Most of these yards have installed advanced material handling, steel cutting and forming, welding and other process technology. The U.S. shipbuilding industry has been extensively involved in the development of computer-aided design and manufacturing and has recently introduced various advanced manufacturing management and control technologies.

Lack of access to cr availability of technology is therefore not the reason for the continued lack of improvements in U.S. shipbuilding competitiveness and productivity. Labor productivity in terms of manhours per unit of output is only 40% of that achieved in Japan, and 82% of that of Korean yards. U.S. shipyard overhead costs, which include administration, inventory, underutilization, and other costs, are significantly higher than those of comparable yards abroad even though most U.S. yards have access to advanced manufacturing management technology such as Materials Requirement Planning (MRP), scheduling, and other systems, and most basic advances in expert systems of potential use to shipbuilding originated in the U.S.

WINDOWS OF OPPORTUNITY FOR U.S. SHIPBUILDING

We are now entering a period of increasing demand for newbuildings (or vessel life extension) as the world shipping supply/demand balance continues to shrink in all types of shipping and few, if any, new large vessel shipbuilding capacity is under development anywhere.

At the same time world trade has and will continue to become freer with new and longer trade routes opening up all the time. Foreign trade with Eastern Europe and the U.S.S.R. alone is expected to add over half a billion tons or 12% to seaborne trade over the next 8 years.

Currently used foreign shipbuilding capacity in Japan, Korea, Western Europe, Taiwan, etc., is

barely able to satisfy ship replacement requirements. In fact, by 1992, the only underutilized large ship shipbuilding capacity will be in the U.S. At the same time, shipbuilding input or factor costs in the U.S. will be as low or lower than those of other major shipbuilding countries. This provides a unique opportunity for U.S. shipbuilding to reenter international commercial shipbuilding. This opportunity, though, will not last.

To take advantage of it will require a radical change in the way U.S. shipbuilding is organized, managed, operated, and does business, including the way it markets its products and procures its inputs. It requires learning from the past and designing for the future, and focusing on shipbuilding as an integral manufacturing system. Piecewise technology adoption to solve narrow or parochial problems so prevalent in the recent past have often caused new and sometimes more serious problems. This approach must be replaced by new collaborative methods in which product and process technology is developed and effectively used by cooperation among clients, shipbuilders, workers, suppliers, and government or regulators.

This will require breaking down of barriers of mistrust which invariably led to adversarial relationships between:

- clients and shipbuilders;
- shipbuilders and suppliers;
- shipbuilders and regulators; and,
- shipbuilding management and workers.

It is important that all parties are involved and/or considered in product and process developments.

Most essential is the improvement of U.S. shipbuilding productivity. As shown in Table 5, an average U.S. yard requires 2.31 as many manhours of direct production labor and 2.3 times as much time to deliver the first of a standard 80,000 DWT tanker as a typical Japanese shipyard. There is simply no justification for this discrepancy. In fact, if larger indirect manhours, including external design costs, are included, the manhour differential jumps from 2.31 to over 2.68.

CAUSES OF LOW U.S. SHIPBUILDING PRODUCTIVITY

Productivity in U.S. yards is affected by several historic, institutional, and structural factors.

Casual methods of hiring and firing of production or hourly labor are a historic anomaly which has no place in modern shipbuilding, in which the vast majority of the workforce must be highly skilled and trained to operate particular and often sophisticated machinery or processes.

Table 5 - Comparison Of Productivity

(Base line Of 1.0 for Japan, unless otherwise Specified.)

Item	U.S.	Japan
Ships	(In the Case Of construction Of five 80,000 DWT Class tankers)	
Area of Plant	2.5	1.0
Travel distance Of materials	5.0	1.0
Number of built-up blocks	209	250
Period required for delivery Of the first Ship (after contract)	140 weeks	60 weeks
Manhours	2,374000 H (2.31)	594,000 (1.0)

U.S. superior points: Outfit, piping Construction
U.S. Inferior Points: designing techniques, Casting techniques, production Control

Source: U.S. Maritime Administration

To be productive, such a workforce should be permanently employed, with unskilled or lower skilled labor hired through contractors. Labor turnover in U.S. yards is many times that of Japanese, Korean, and European yards. It has always been significantly higher (by a factor of 3-4) even during times of fairly steady shipyard employment. (Hiring and firing contribute significantly to overhead costs and reduce productivity as new hires or workers under notice will not achieve their normal productivity).

A related issue is the quality of the existing workforce. U.S. shipyard workers are, on average, older (37.8 years) and less educated than in other major shipbuilding countries. Although 73% have finished high school, basically none have college education, even among production foremen and floor managers. Very few have the basic statistical skills required for effective quality control and a significant percentage are functionally illiterate, even among high school graduates. Yard-provided training is usually confined to narrow skill enhancement and not education.

Another important issue is labor-management relations which are often adversarial. Effective mutual communication required for effective operations is often lacking, nor do labor and management recognize mutually beneficial objectives. The

strong role of unions is a major factor. Shipbuilding unions have, for example, opposed job security or permanency, as it would deprive union leadership from using seniority as a power plan. This in turn results in newly hired highly skilled workers to be laid off before older less skilled workers.

Also, proliferation of unions (often more than 7 unions organize labor in a U.S. yard) results in destructive restrictive job definition which reduces management's ability to use labor productively.

Unions also often obstruct introduction of new technology and require workers to be relegated to task oriented labor. Similarly, communication barriers among labor and management and their induced conflicting interests stymie effective feedback from the shop floor, something which is essential for productivity improvements.

Shipbuilding unions are among the last narrowly organized craft type unions in the U.S. Their organization, work rules, and skill or job definitions are out of line with actual work requirements in today's shipbuilding.

As a result, new technology is not always effectively operated. It also causes insufficient cooperation among people using technologies or processes which only perform well if effectively integrated. Shipyard process innovation and technology adoption (both hard and soft) appears to be random and mostly motivated by individuals interested in specific areas. There is little evidence of overall strategies or management of technological change, and most shipbuilding process innovation is adopted from abroad. While there is nothing wrong with copying or adopting technology, it must be done systematically and not haphazardly. Furthermore, drastic technological change, as introduced in many U.S. shipyards in the last two decades, requires structural and organizational change as well as effective training to be effective.

There has been no noticeable change in the way U.S. yards are organized, managed, and manned. This may in part be the result of the piecemeal introduction of technological change, though it could also be argued that the piecemeal change was induced by the lack of desire or ability to introduce organizational and management changes. This at a time when most major U.S. industries have introduced radical changes in their organization, management, and procedures. In these industries, job security and worker management collaboration has been introduced not only in quality circles or other work process oriented relations, but many industries have integrated the basic roles of workers and management.

Wherever unions resisted such changes they were usually the losers. U.S. union membership is now only 17% of workforce and expected to decline to 15% by 1995. Yet average annual salary increases by non-union labor has been 10% higher than that of union labor.

Another issue causing low productivity appears to be the U.S. shipbuilding approach to product development and marketing. Most ships constructed in U.S. yards are customer designed which often causes difficulties with efficient production or requires redesign for producibility. This not only causes added costs and addition of time, but may also result in undue numbers of unforeseen change requirements during construction.

Although these penalties are mainly assumed by the first ship of a series, later vessels suffer because of the resulting long time delay, which often causes built-in obsolescence in following ships, which in turn may induce clients to require a change to bring the vessel more up to date.

Marketing and selling mainly to the government also introduces various constraints which affect productivity and competitiveness. The industry has become used to doing business the government way. Its approach to cost estimating, material and equipment procurement, quality management, and production control are all affected by modeled after often archaic government procedures and requirements.

Marketing has also become highly politicized with many decisions and approaches to marketing and production based on political requirements and not technical and commercial considerations. These requirements are obviously also major causes for top heavy and less than effectively integrated shipbuilding management, excessive administration, and slow and often unresponsive control of shipbuilding progress.

The different causes and their contribution to low yard productivity

and competitiveness (or high cost of production) are:

1. casual labor practices and high labor turnover;

2. ineffective marketing, customer communications, long shipbuilding lead time, and customer control over design, and certain procurements;

3. ineffective, non-responsive, hierarchical organization and management structure;

4. comparatively low level of education and training of workers, staff and management;

5. lack of effective operational integration and intra labor as well as labor-management communications and cooperation;

6. inadequate yardwide strategic planning of technological change or piecewise technology introduction;

7. ineffective procurement and inventory management;

8. lack of total quality management;

9. restrictive union practices, such as work rules, seniority systems, and opposition to technological change, or changes in work procedures;

10. lack of effective design/production integration or design for producibility;

11. short horizon management; and,

12. lack of discipline, loyalty, and commitment by staff and workers.

It is interesting to note that Japanese yards nearly doubled labor productivity since devaluation of the dollar against the yen, and therefore continue to be competitive in international ship sales. At the same time, relative productivity of U.S. yards has declined - they are today no more competitive than they were before the dollar devaluation against the major world currencies during 1987-89.

Only by drastic elimination of the above identified root causes will U.S. shipbuilding achieve world class excellence and productivity. Changes in the causes will have severe political repercussions, but we must harness the courage to face these.

This is not an easy task for an industry long sheltered from real competition by captive markets, government protection and direct as well as indirect government aids. But the reality of declining defense needs, unavailability of government subsidies, and increasing openness of world trade requires a reorientation of the industry if it is to survive and play its rightful role in the U.S. and world economy and defense.

POTENTIAL FOR U.S. SHIPBUILDING COMPETITIVENESS

What I propose is a radical overhaul and change of the structure, management, work rules, employment and business as well as marketing practices of the industry. Many may say that this cannot be done. Yet some of the most well known firms and industries in this country have done it or are in the process of doing it.

The U.S. automobile industry, which lost 29% of its domestic car market to foreign imports and cars made by U.S. based foreign automakers, has completely restructured itself, led by Ford and Chrysler. Their productivity in terms of cars produced per man/year or similar productivity measures has doubled in the last 4 years. It is still less than half that of their Japanese competitors, even those manufacturing their cars in the U.S., such as Honda, Toyota, etc., but they are well on the road of competitive improvements. Much larger improvements have been achieved by Boeing, Motorola, IBM, DEC, and scores of pharmaceutical firms. All of these have restructured radically.

The fact is that even with these major achievements value added per employee year in U.S. manufacturing is $90,000/employee year, still well the $198,000/employee year achieved by Japanese manufacturers (1989). Unless we manage to close this gap, and it can no longer be done by currency exchange adjustments because the U.S. economic clout has eroded too greatly, U.S. standards of living and economic position will be endangered. Similarly, the survival of complete industries, such as shipbuilding, will be at stake. The outbreak of peace and an increasingly open unregulated world trading environment will

increasingly deflect support for maintaining non-economically justifiable industrial activities on the basis of national defense and economic security. But U.S. shipbuilding can be made competitive again, if there is enough will, commitment, and cooperation among all the stakeholders in the industry.

REQUIREMENTS FOR U.S. SHIPBUILDING EXCELLENCE

U.S. shipbuilding has to transform itself into a free enterprise, commercially viable world class competitive industry which is at the forefront of shipbuilding product and process technology and operates without dependence on and interference by government. It should evolve as an industry meeting world and not only U.S. defense needs, by independently developing advanced naval systems designed and produced wholly by the industry and not custom built to a client-developed design. Obviously client (U.S. and foreign navy) strategic and tactical requirements and specifications should be considered, but the industry should respond to these by developing responsive systems themselves, and not build to navy designs, which often evolve over an undue long time, with built-in obsolescence, and are often difficult to produce without major design modifications. At a time when complex military aircraft, missile, ground warfare and other military systems are designed by their manufacturers, there appears little need for navy (or navy contractor) design of naval ships.

Shipyards should develop designs for naval ship markets which they are best equipped to deliver. Designs thev can effectivelv build and themselves arrange for all procurement. The government may provide research and development (R&D) assistance for the development of new naval ship and/or payload systems, but should not itself perform (or guide) systems development and design. Shipyards would maintain close contact with their customers and assure up-to-date knowledge of their future technological requirements, quality and performance needs, and prospective naval ship systems demand.

It is important for yards to maintain control over all stages of the product (naval ship) and production development cycle. When completely new naval ship or ship systems technology is to be developed, then a joint shipbuilding industry research project (much like those in the TV and computer industry) should be undertaken with joint government/industry support, in which all relevant resources and capabilities are pooled. Similarly in commercial shipbuilding, yards should develop their standard products (ship designs) equipped with standard outfit suites and machinery. They should market these standard designs with as few options or extras as possible and arrange for efficient just-in-time delivery of all procurement or buy-in items and services. This will allow yards to reduce order to delivery time, procurement and inventory costs, and finally improve productivity and quality. It would also allow yards to specialize in ships or products most efficiently and effectively built in their facilities.

It furthermore would permit yards to be involved in ship technology development which is a prerequisite for effective ship production technology development and use.

U.S. shipyards are distinct in their lack of involvement in basic ship design and technological developments. Designs and engineering affect productivity, quality, and costs. Design affects material choice, method of processing, joining, forming, machining, assembly and outfit and, as a result, locks in all important decisions affecting productivity, schedule, quality, and costs.

In fact, design, engineering marketing, production, procurement, and management must be effectively integrated with workers and staff involved in all functions or at least rotated through these various activities to assure more effective understanding and cooperation as well as quick resolution of problems.

To achieve this, the hierarchical type organizational structure used in U.S. shipyards may have to be radically changed, flattened, and made more flexible, to allow better communications, more effective decision making and greater flexibility of operations under continuously changing conditions.

This obviously also implies new open, trusting labor-management relations, job security, profit sharing, effective recognition, and other motivating inducements. As a result, unions or the union will have a completely different role. Its function will be to help coordinate labor management relations and assure that the joint interest of labor and the yard is 'always recognized and

maintained. Unions must also play a greater role in motivating their members and assuring responsiveness as well as discipline.

Shipyards should invest more in training and attempt to hire more highly educated workers and staff. Shipyard training must become a continuous process by which worker's and staff's technological abilities are advanced all the time.

U.S. shipyards should require strict schedule and delivery adherence to assure that all possible conflicts are resolved before the start and minimize or eliminate changes in design, material, equipment, supplier or other.

Over 30% of the cost difference between U.S. and Japanese yards, for example, is caused by change order, late supply delivery, or other schedule delay and the resulting loss of productivity. If inventories in U.S. yards could be. reduced to an average of one month requirements (versus 6 days in most Japanese yards), if deliveries enforced voluntary or client-imposed change orders were eliminated, and the schedule tightened, then over 48% of the time to delivery could be saved, and delivered costs reduced by 30%, of which about 12% would be reduction in construction cost financing and 18% saving accruing from reduced inventory holding costs and improved productivity (Ref. 1).

To verify these numbers we use Japanese shipyard cost and performance figures, and computed the increase in costs if a Japanese yard were to operate with the same long inventory, unreliable procurement deliveries, large numbers of change orders, etc., or in other words, the conditions currently by typical U.S. yards.

To achieve excellence U.S. yards have to introduce technological change in management, production, marketing, and engineering in a systematic and piecewise manner. Computer Aided Design/Computer Aided Manufacture (CAD/CAM) flexible manufacturing, quality circles, and other recent developments do not achieve their promise unless introduced together with changes in institutional structure, delegation of authority, improved communications, motivational incentives, integrated marketing design, and engineering, worker and staff discipline, new process technology, etc. Similarly quality cannot be achieved by isolated quality control or quality circles. Quality must be a total commitment involving all activities of the yard.

As mentioned before, other U.S. industries have turned around and achieved total productivity improvements of 2-3% Per month. The same is possible in U.S. shipbuilding with courageous commitment to change. There is nothing wrong with U.S. labor or management. As individuals, we perform as well as the best. It is the way our shipbuilding industry is made to work which is to blame.

Our lack of productivity is not the result of individual incompetence or lack of ability at all levels in a shipyard, but the accumulation of factors which together do not permit individuals, facilities, processes, etc. to perform at their full capacity and to the best of their ability. A worker without adequate tools, materials, or direction cannot perform his job. Our industry suffers under a consistent hangover of factors which do not allow it to perform at its best. We need a radical change to provide us with that opportunity.

GUIDELINES FOR A WORLD CLASS U.S. SHIPBUILDING INDUSTRY

A number of guidelines or goals are suggested which are designed to move U.S. shipbuilding to a state of a world class industry. Such guidelines, to be effective, must be followed all together, as piecemeal introduction would not serve. These guidelines complement and support each other towards the achievement of radical improvements in productivity, cost, and market share.

(1) People are the most important factor of production. Technology can give them better tools but ultimately people determine output. People affect product and productivity and ultimately profit (P.P.P.). People must be motivated. Recognition, reward, and appreciation are necessary to motivate people. People in a yard must understand all the functions of the yard, the needs of the customer, the role of the product. People must be proud of their association with the yard and the products of the yard. They must have a feeling of belonging, contribution, and security. they must be given all opportunities for training, communication, and advancement - Total Employee Involvement.

(2) Management should be organized to reflect decision requirements and not meaningless

hierarchy. Management serves workers and is there to facilitate their work and not the other way around. Technological and other changes should be suggested by the users of technology and not the managers. Management has responsibility for strategic improvements.

(3) Workers and managers all have to be involved in selling and in customer understanding and relations. Similarly, quality is defined by the customer, but quality requirements must be imposed on design, engineering, suppliers, manufacturers, etc. Total quality management improves productivity as it reduces waste in all the different activities.

(4) Inventory is waste and must be kept to a minimum. Inventory does not improve process or resource utilization, but only covers up ineffective scheduling, line imbalance, and other ineffective management. Improved total quality, effective scheduling, just in time supplies, and resulting low or zero inventory will also greatly reduce scrap.

(5) Production time must be compressed to a minimum to

a. maximize resource utilization;
b. reduce in process (construction) financing cost;
c. minimize built in obsolescence;
d. reduce scrap and other waste;
e. assure achievement of quality;
f. maintain technological advance at highest level; and,
g. achieve maximum total productivity, highest profit, and largest market share.

Wasted time or time delay caused by scheduling, late deliveries, change orders, lack of management or worker discipline, or other will have multiplying effects on productivity and cost.

(6) Supplies should be single source and suppliers included in the total product development, as well as quality and production schedule management.

(7) Use of integrated product and manufacturing design teams consisting of sales, design, engineering, manufacturing, and management staff should be encouraged.

(8) Maximization of concurrent design, engineering, and process development and feedback learning.

Reduction of bureaucratic bottlenecks by limiting data collection, transfer and storage to that actually required. Train all people in basic statistical methods for self-evaluation of performance and quality.

Achievement of these goals requires commitment from top management which must convince staff and workers that these goals are irreversible, will benefit all, and that benefits will be shared by all.

RECOMMENDATIONS AND CONCLUSIONS

It is not possible to spell out a detailed plan in a short paper, and therefore an attempt was made to only identify the issues, illuminate the opportunities, and define some essential goals which could revitalize the U.S. shipbuilding industry. Improvements in total productivity of 2-3%/month are achievable, as are development of new product (ship) and production process technology. The U.S. has introduced the most advanced ship technology only to have others benefit from it.

It is necessary for us to emerge from our sheltered parochial (and often paranoid) position and assume a can-do and prideful pose. There is no reason why U.S. shipbuilding cannot effectively compete in world shipbuilding if we set our mind to it, ignore the past, and work toward the future, with commitment, price, hard work, courage, and imagination.

Most important, the U.S. shipbuilding industry will have to be more commercially oriented and loose its obsession for government aid, support, and contracts. The industry not only spends an inordinate amount of time and money on government relations and political support, which if spent on product development, marketing, and restructuring may go a long way in making it commercially competitive. Dependence on the government budgeting process results in major instability while reducing the industry's leverage with labor.

The U.S. shipbuilding industry is an anathema in today's free enterprise world where industries

worldwide move rapidly from dependence on government decisions and government generated business. The U.S. shipbuilding industry can become commercially competitive, given its capability.

A five-year transition period may be required to restructure the industry. One possibility to facilitate this transition would be to create a Shipbuilding Capital Corporation, a joint government-industry group backed by a federal loan guarantee of say $2 billion, which would develop:

(1) a new organizational and business structure for the U.S. shipbuilding industry;

(2) perform advanced ship and shipbuilding concept research;

(3) design several American standard ships of the future;

(4) restructure the U.S. shipbuilding supply system;

(5) retrain shipyard managers and workers; and,

(6) develop effective strategies for marketing U.S. shipbuilding worldwide.

The loans would be repaid from license fees, royalties, sales commissions, and so forth.

Unless we move in this general direction, I feel that the future of the industry is dim indeed, as we cannot rely on a continuous and adequate flow of navy work nor effective government support in the future.

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Plister Hotel, Milwaukee. Wisconsin, August 21-24, 1990

An Assessment of Opinions on Producibility within the Naval Sea Systems Command (NAVSEA)

8B-1

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An Assessment of Opinions on Producibility within the Naval Sea Systems Command (NAVSEA)

by Richard Byrnes and Henry S. Marcus

lntroduction

After years of studies, reports, formal and informal discussions, Naval ship producibility is becoming accepted as a necessary ingredient in any recipe for affordable, effective warships. However, within both the Navy ship design and private ship construction communities, the word "producibility" has come to evoke a wide variety of reactions. While there is general agreement that producibility has to do with lowering ship costs, there is not yet a consensus on how those costs are to be attacked, what factors are the most important, and what the roles of the various participants should be.

In order to answer these and other questions, and to form a consensus within the Navy design community that will be compatible with external as well as internal relationships, the Naval Sea Systems Command (NAVSEA) has sponsored a series of steering committee meetings and a workshop on producibility as part of its ongoing research. The purpose of these meetings and workshop is to clarify the meaning of producibility, the needs of the design and construction communities, and to determine critical actions which will enable NAVSEA to integrate producibility more thoroughly into the Naval ship design process.

In support of this consensus building effort, a survey was conducted to help understand the opinions of the NAVSEA community on producibility. Producibility is a multifaceted consideration which is influenced by several disciplines and which is often the subject of debate. Tabulating the survey results would allow members of the community to view the overall range of ideas and opinions which are held by individuals. Subsequently, understanding the current thinking on this topic within NAVSEA can help establish a baseline from which the formulation of producibility goals and plans of action to achieve those goals can be set. Identifying areas where there is agreement, disagreement, and indifference can help design policy makers and designers to better realize where strengths lay, and where changes need to be made. This paper describes the survey methodology and results.

Survey Methodology

Surveys are an efficient and widely accepted means of gathering information to assess group opinion, support decision making, and conduct research. The survey methodology is composed of three steps: survey design, data collection, and data analysis. The first step, survey design, consists of establishing the purpose and targeted sample of the survey, determining the appropriate methods of data collection and analysis to be used, and defining informational needs.

The sample of respondents was a purposeful, non-probability choice, in that it was not chosen to exactly reflect the general NAVSEA population. Respondents were selected because they were deemed to be experts who are critically influential in the NAVSEA ship design and acquisition process and/or on the role that any NAVSEA producibility efforts would play in that process. In other words, it was sought to assess the thinking on producibility of those NAVSEA professionals who may be in a position to do something about it. We do not claim to have surveyed every influential person in NAVSEA, but submit that the sample consists of sufficient diversity and size to represent the range of responses and ideas that may exist regarding producibility opinion.

Of the applicable data collection techniques, which include interviews, questionnaires, observation, and sample content analysis, the producibility survey consisted entirely of questionnaires. This was determined in the interests of both economic efficiency, and the fact that desired respondents were very busy and worked in many locations, such that other techniques would be prohibitively difficult to implement.

The substance of the survey is the informational needs, and these were determined and formulated into three components: administrative information, opinion areas of interest, and respondent comments. These components were then formulated to fit the questionnaire format, and the result was pilot tested in the hope of correcting any ambiguities or other implementation problems.

With the first component of the questionnaire, administrative information, we sought to compile data on the sample make-up, including determining the amount of experience in Naval activities and in producibility that respondents had. The producibility survey was conducted on a sample that was limited to NAVSEA personnel, but within this sample, a wide variety of professional disciplines was represented.[1] Anonymity was guaranteed.

For the second area of informational needs, five key decision making areas were determined and were formulated into a series of thirty-four hypothetical statements, plus two sections requesting respondents to quantify design priority tradeoffs between selected design factors. These five areas of interest are:

- Assess perceptions of the definition and role of producibility for NAVSEA.
- Assess perception of resource availability and needs.
- Assess perception of needs for shipyard activity in the NAVSEA design process.
- Determine perceived design priorities.
- Assess opinions on selected policy options.

The third component was to collect respondents' comments to aid in making a qualitative assessment of perceptions on producibility.

Each of the thirty-four statements was designed to address an individual issue within one of the five areas of interest. The response was measured as a preference on a five point interval scale: (strongly disagree, disagree, neutral, agree, strongly agree]. The data from these were compiled and resulted in numerical totals for each of the five possible responses, along with the statistical measures of mean and standard deviation (s). From these measures, the degree to which the respondents agreed or disagreed with the statement can be determined, as well as the extent to which the respondents agreed with each other, indicated in the "spread" of answers.

[1] Some non-NAVSEA personnel participated in the survey during pilot testing, providing valuable insight into the survey content. However, in the interest of clarity, this paper describes only results of NAVSEA respondents.

The design priority sections were included to establish the range of opinion concerning which design considerations were the most important. Examining the results can help to determine areas of agreement and disagreement with established design policy, and this in turn can help decision makers clarify to the community as a whole where the emphasis in design should be.

One design priority section was a round robin series of six "one-on-one" trade-offs between the macroscopic design priorities of acquisition cost, lifecycle cost, ship mission performance, and construction time. Each tradeoff was to allocate 100 points between two alternatives (e.g. 'lifecycle cost' vs. 'construction time'). In the other design priority section, respondents were requested to rank thirteen common design considerations (plus any other considerations the respondent may have wanted to list) according to an ordinal scale (1 for best, 2 for second, etc.). A ratio scale was then used as the respondent was asked to allocate 100 points among the same considerations.

After initial pilot testing, the survey was introduced in April 1989, and fifty-five responses were collected between then and November 1989. One respondent commented that the questionnaire required about an hour to finish, thus these results represent a considerable investment into the knowledge base on producibility.

For all three components of the questionnaire, data analysis consisted of numerical and statistical analysis for quantifiable variables, and identification of common factors, qualities, or comments for qualitative aspects of the sample responses.

Discussion of Survey Results: Administrative

The survey results are comprised of the responses of fifty-five professionals involved in the Naval ship design and acquisition process. The reader can see from Table 1 that the sample was a well educated and well experienced one, and which had a diversity of responsibilities in the process. The range of respondents' occupations included design engineer; ship design manager; program manager (PM) and assistant PM; project and division directors; research and development; and executive directors at the highest levels in NAVSEA directorates. Their active projects include submarine, surface warship and auxiliary

ship design, with specialties in hull, mechanical, and electrical (H, M & E), weapon systems, and financial/accounting practices.

PRODUCIBILITY SURVEY SAMPLE	
NO. OF RESPONDENTS:	55
MILITARY:	4 (7%)
CIVILIAN:	51 (93%)
HAD PREVIOUS PRODUCIBILITY EXPERIENCE	32 (58%)
YEARS AT NAVSEA AVG:	18.0
TOTAL YEARS IN NAVAL ACTIVITIES AVG:	21.4
HAD EXPERIENCE IN:	
ACCOUNTING/BUDGETING/SCHEDULING	27%
DESIGN ENGINEERING	89%
EXECUTIVE MANAGEMENT	31%
MID-LEVEL MANAGEMENT	80%
MATERIAL CONTROL/DOCUMENTATION	7%
PRODUCTION PLANNING	18%
PRODUCTION WORK	9%
EDUCATION:	
HIGHSCHOOL	100%
ASSOCIATE'S DEGREE/TECHNICAL SCHOOL	
BACHELORS DEGREE	96%
MASTER'S DEGREE	56%
DOCTORATE	
LAW DEGREE	0%

Table 1

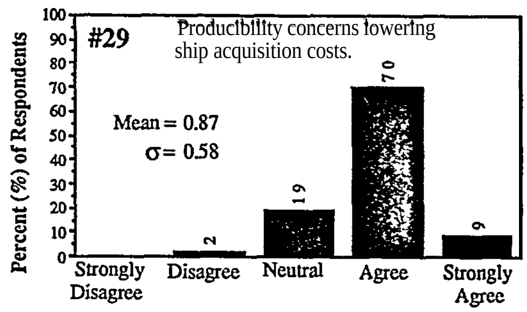
An interesting note on the sample was that 58% of the respondents had been involved with producibility efforts in the past. The range of these efforts included the DDGX producibility feasibility studies, as well as studies for CVNX and CVN71, FFG-7, CG47, DDG963, T-AGOS 19 and 23, SWATH T-AGOS, AOE-6, T-A0 Twin Skeg Concept, the Ships Systems Engineering Standards (SSES), TRIDENT, SSN688, and SEAWOLF.

A perhaps more interesting statistic is that less that a tenth of those responding indicated having any production work experience, and less than a fifth had experience in production planning. By contrast, the group had extensive engineering, design, and management experience.

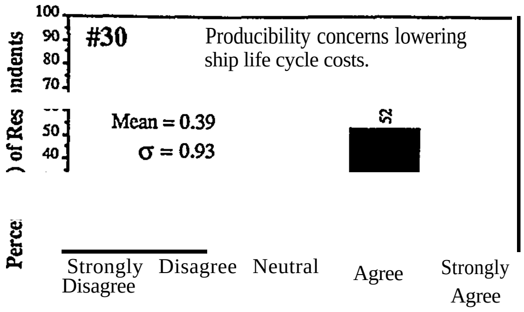
Discussion of Survey Results: Opinion Areas of Interest

Regarding the thirty-four opinion statements and design priority sections, we have tried to group them in a logical arrangement that will help identify areas of strong group agreement, disagreement, consistency and inconsistency. The quantitative measures of mean and standard deviation (s) are based on a numerical value assignment of (-2, -1, 0, +l, +2) to the categories: (SD, D, N, A, SA). When looking at these graphical results, we suggest that, though the statements and their response analysis are subjective, criteria for strong group consensus may include a mean value significantly far from zero, a relatively low standard deviation (indicating a smaller spread of opinions), or if the sum of the 'agree' and strongly agree' categories (or disagree and strongly disagree) represents a significant majority or very small minority.[2] (Where appropriate, pertinent respondent comments will be included in this section, with general comments reserved for a later section.)

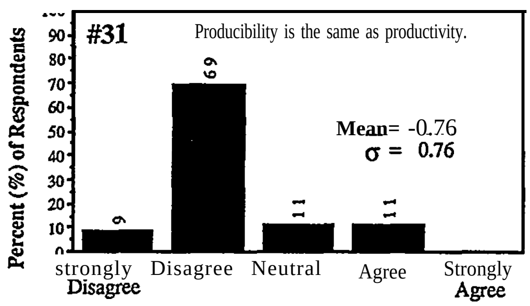
Beginning with the ideas of the definition and role of producibility, statements 29, 30, and 31 along with statements 9 and 10 give some idea as to the general perception of what producibility is. Within NAVSEA, the definition that producibility concerns lowering ship acquisition costs is widely accepted, and this is reaffirmed by the response to statement 29. However, statement 30 shows that although most respondents felt that producibility concerns reducing lifecycle costs, there is some &agreement on this matter.



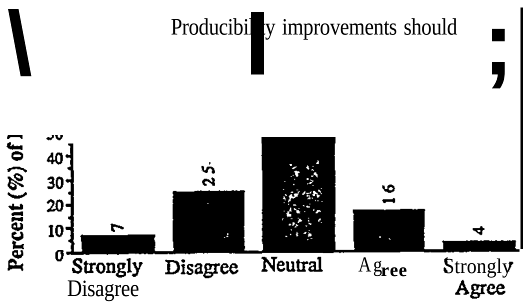
2 In the interest of conciseness and to avoid possible confusion, the illustrations for the 34 opinion statements will be identified by their statement number in the upper lefthand comer, and not the conventional Figure 1, Figure 2, *etc.*, scheme.

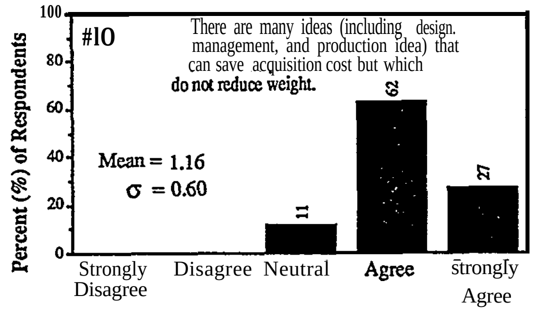


Statement 31 affirms the difference between producibility and productivity. The former deals with inherent properties of a design and the process of producing the designed product. The latter deals with the relative ability of a workforce to manifest those properties.

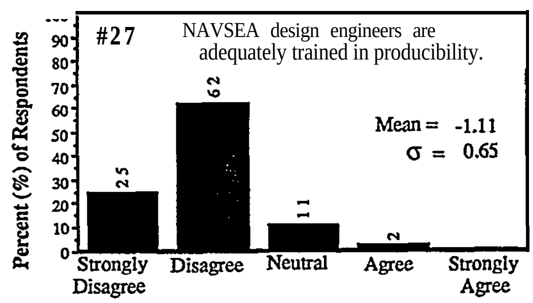


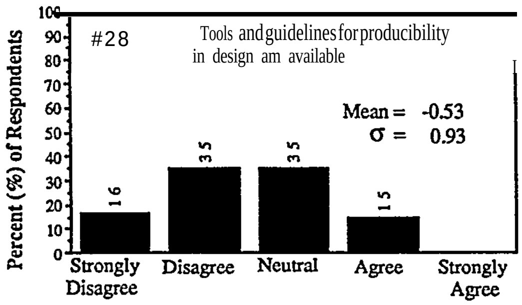
Traditional cost models, which are highly weight dependent, may lead one to believe that if producibility concerns lowering acquisition costs, then one should focus on reducing the ship weight. This traditional logic is refuted by the dispersed reaction to a correlation of an emphasis on weight reduction with producibility improvement in statement 9, and the strong agreement to statement 10 that there are many concepts that can save costs but that do not save weight. This suggests that traditional costs models may need to be reviewed for ways of incorporating producibility dependent parameters.



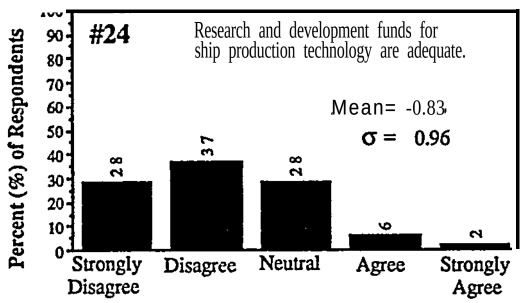


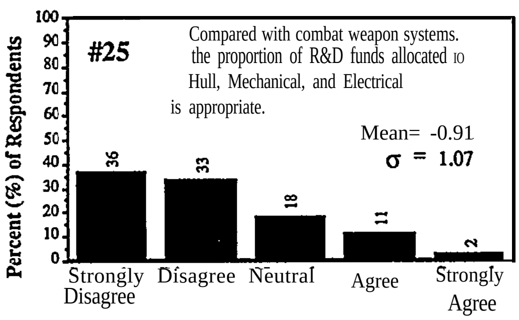
In order to assess the perception of resource availability and resource need, including training needs, we presented statements numbered 24-28 for opinions. Statements 27 and 28 show that there is very strong opinion that NAVSEA engineers are not trained well in producibility, and that there is probably a need for more and/or better tools and other guidelines to train engineers with.

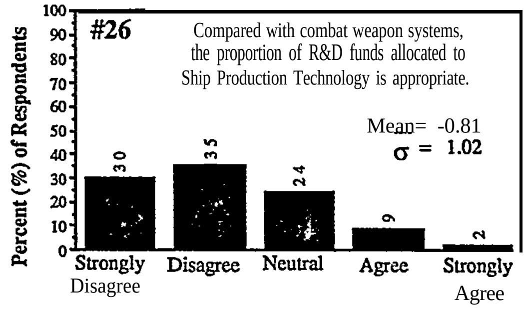




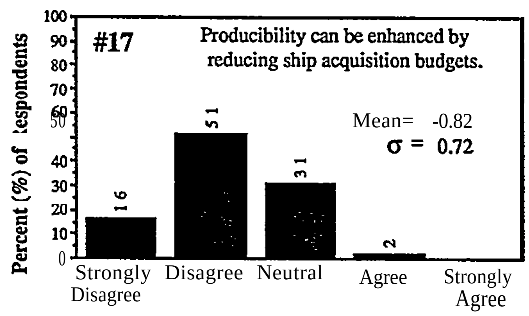
Statements 24, 25, and 26 indicate strong opinion to the effect that the dominant share of research funds available is directed toward weapon systems vis a vis ship production technology and H, M & E.

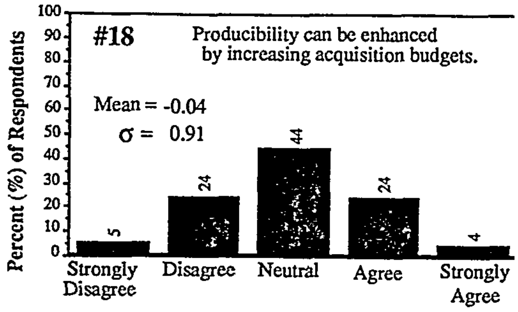




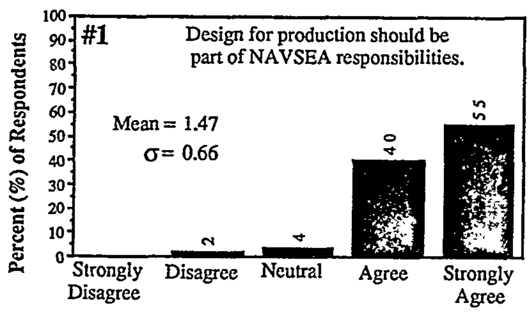


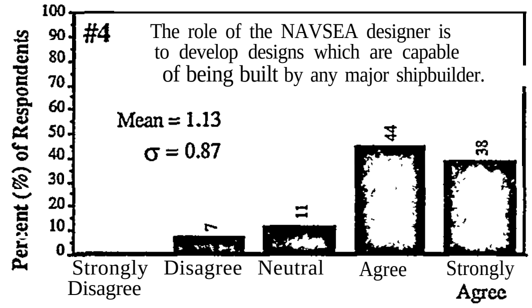
The conclusion that ship designers would like to have more money to devote toward research and development may be foregone. A strong disagreement with statement 17 that producibility can be enhanced by spending less on acquisition reinforces this attitude that a smaller acquisition budget will not enhance producibility. But the near-normally distributed response to statement 18, which queried the need for increased funds for acquisition, possibly indicates that producibility may not be a "money problem" after all. Perhaps the answer lies in how the money is spent.



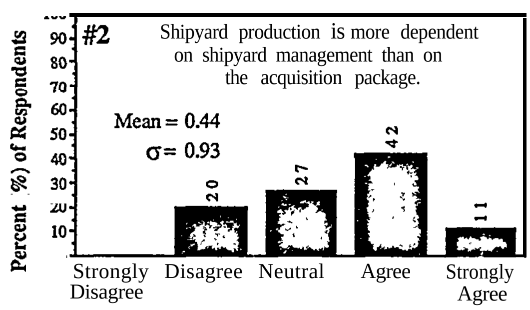


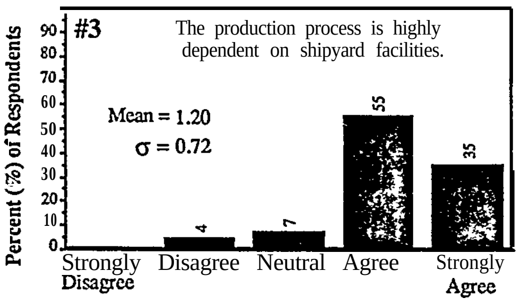
This leads to the question of how the NAVSEA designers and other personnel should treat producibility in the design and acquisition process, or what the role of producibility should be. Statement 1 brought strong agreement that design for production is a NAVSEA responsibility. The goal of design for production is an easily produced product. The results of statement 1 are, however, contrasted by those of statement 4, which show equally strong agreement that a NAVSEA design must be independent of the capabilities of any particular shipbuilder.



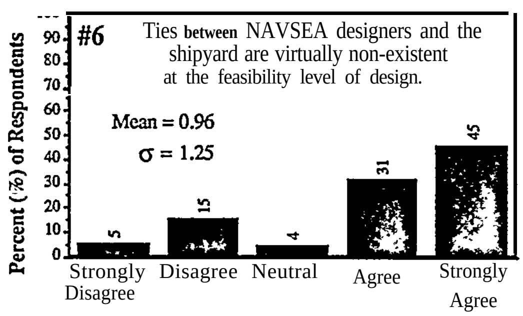


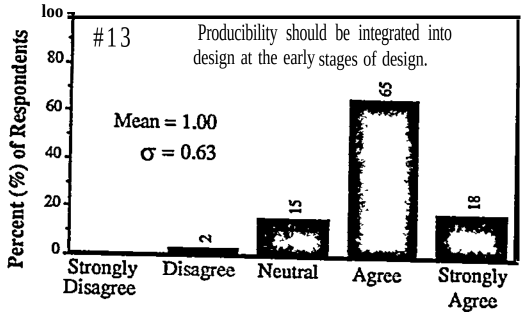
There is a difficult inconsistency in that one cannot design for production without knowing the production process and facilities to be used. This is reaffirmed by statement 3, in which 90% of NAVSEA respondents agreed that production is highly dependent on the yard facilities. Further disagreement as to whether it is the acquisition package or the shipyard management which affect production most is indicated in the dispersed response to statement 2. It appears that clarification regarding the input of shipyards would be helpful.



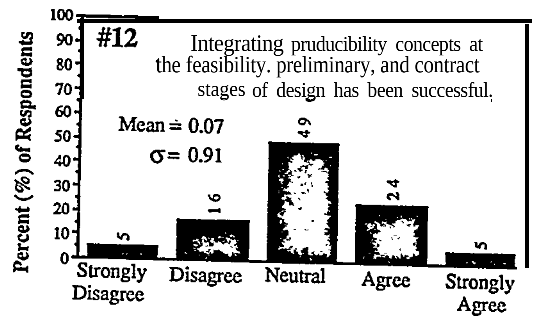


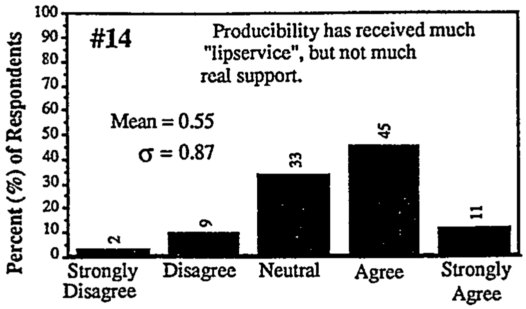
If the shipyards have a significant amount of influence on the outcome of the ship acquisition costs, then a couple of questions might be: 'How do NAVSEA and shipbuilders communicate?', and 'What can be done to assist interaction between NAVSEA and shipbuilders?'. Several statements attempt to address these issues. The bi-modal response of statement 6 indicates that, while there is strong agreement *(over* 70%) that there is little interaction between NAVSEA and the yards at feasibility studies, there is a significant portion of respondents that think there is interaction. Further analysis of this data showed no significant correlation with these latter respondents and their working groups or occupations. It is possible that either these respondents may have worked together at some previous point and thus formed their opinions based on that experience, or that NAVSEA-shipbuilder involvement occurs on an individual case basis.



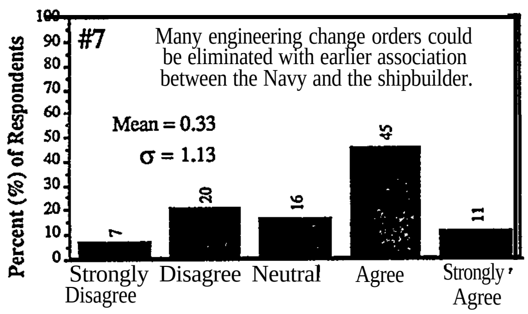


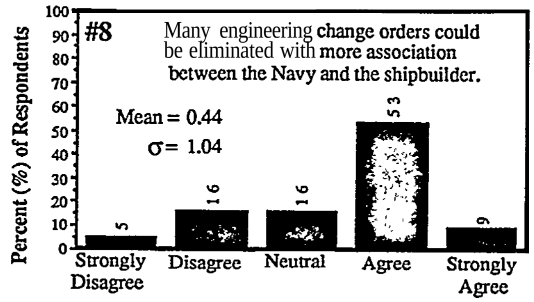
Statement 13 showed strong agreement that producibility should be considered early in design. This could perhaps be assisted by earlier interaction with shipyards. By comparison, the reaction to statement 12, that early producibility consideration has been successful, was mixed. This somewhat neutral response may be explained by the broad nature of the statement. However, after realizing that 56% of respondents agreed with statement 14, that producibility has not received much real support, indifference toward stating success may be better understood.



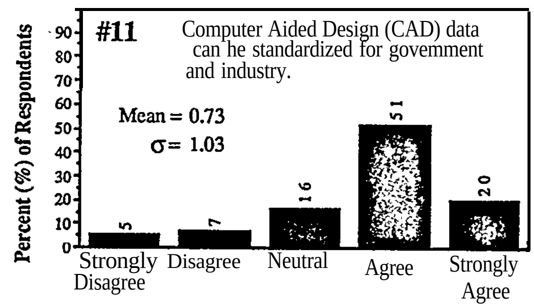


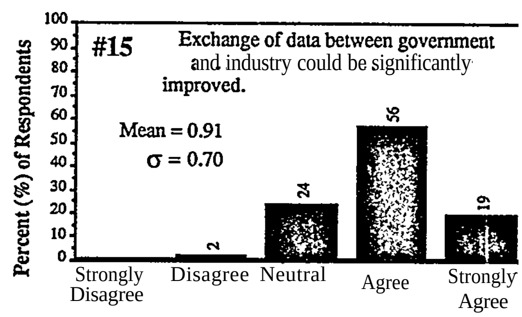
Most respondents agreed that earlier or more NAVSEA-shipbuilder association would result in less change orders. That less change orders will be an indicator of a more producible design is a premise that can be debated. However, the dissent indicated by the bi-modal and nearly bi-modal responses to these statements means it would be helpful to clarify these issues, including the relationships among change orders, shipbuilder involvement, and producibility.





Statements 11 and 15 further indicated a perception that communication between NAVSEA and shipbuilders can be improved.

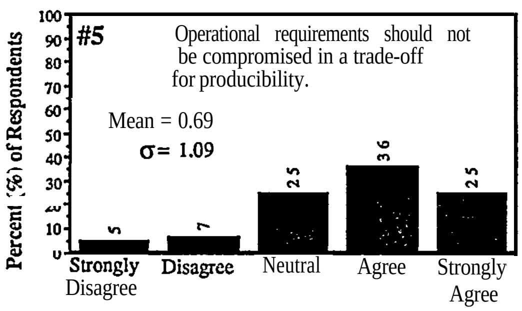




If NAVSEA-shipbuilder relationships play an important role in realizing producibility benefits and improvements, and if the barriers to improvement lay more in the nature of

the design methods, organizational structure, communication lines and cost accounting methods rather that availability of funds, then perhaps further work to identify these barriers to improvement and implement changes needs to be done. Several statements posed some general policy options regarding the design and acquisition process. Other policy options can be inferred from statements previously noted, such as the cost modeling implications of statements 9 and 10, or the explicit call for producibility effort by NAVSEA as seen in the response to statement 1.

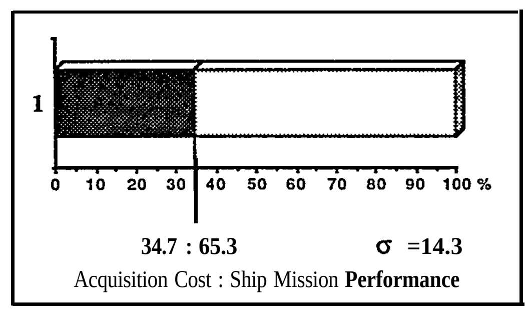
Particular policy options are addressed in statements 5,16-23, and 33-34. The first of these addressed the question of whether mission capabilities should be compromised in a trade-off for producibility. The majority (61%) agreed that capability should not be compromised, yet a full one fourth of the respondents were neutral to the statement, and a significant one eighth disagreed. This issue is a vital one which deserves further explanation, and a few respondent comments can clarify the diversity of opinions. One respondent remarked that "if the ship doesn't meet requirements, [then] why build it?" Another respondent presented a converse view. "if the shin never gets built [because it is too expensive], what good would it be?"

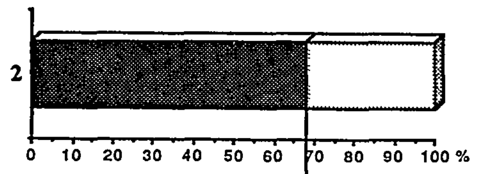


Under the assumption that there are reasonable trade-offs among cost, capability and other factors, an attempt was made to quantify at least some of the major ones. For this purpose we investigated and present here results of the two design priority sections. The first concerns macroscopic design trade-offs among factors of Ship Mission Performance, Acquisition Cost, Lifecycle Cost, and Construction Time. Each of these factors was compared in a "one-on-one" basis with the other three, with the respondent allocating 100 points between the two, resulting in the six bar-charts below. Interesting results include the degree of favoritism of the various factors, represented as the numerical ratio averages, as well as the degree to which individual opinions were consistent with the group average, represented by the standard deviation.

Consistent with the results of statement five is the fact that Ship Mission Performance is "weighted" more heavily in comparison with each of the other factors. Perhaps not surprising is the fact that Construction Time was weighted lightly compared to the other factors given the existing peacetime environment.

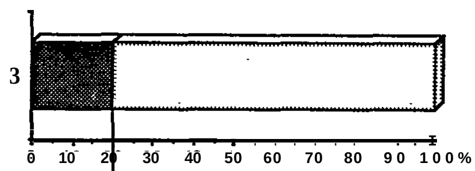
An interesting development among the tradeoff results was a flip-flop of preference concerning the Acquisition Cost and Lifecycle Costs factors. Individual comparisons of both of these costs against Ship Mission Performance resulted in about a two to one preference favoring Ship Mission Performance. However, in these two comparisons, Acquisition Costs received slightly more points versus Ship Mission Performance (a 34.7 share out of 100) than did Lifecycle Cost (a 33.4 share). The flip-flop occurs when looking at the direct comparison of Acquisition and Lifecycle Costs, where Lifecycle Costs received more preference (a 52.3 share).





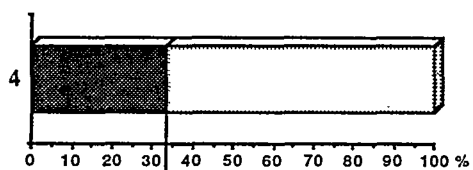
68 : 32 σ = 16.0

Acquisition Cost : Construction Time



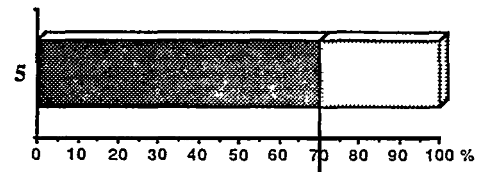
19.8 : 80.2 σ = 11.6

Construction Time : Ship Mission Performance



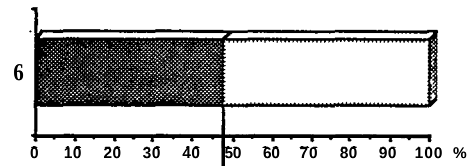
33.4 : 66.6 σ = 15.4

Lifecycle Cost : Ship Mission Performance



70.2 : 29.8 σ = 18.7

Lifecycle Cost : Construction Time



47.7 : 52.3 σ =20.4

Acquisition Cost : Lifecycle Cost

A similar analysis in comparing the two costs with Construction Time results in Lifecycle Costs having a slight preference, a 70.2 share versus a 68 share for Acquisition Cost, which affirms the direct comparison with no flip-flop. The sort of flip-flop, or non-transitivity in preferences, can be attributed to the complexity of assessing group preference, and is similar to the Arrow Paradox in which group preferences of the sort (A over B, B over C, and C over A) result from mixed individual choices.[3]

Perhaps one important point is that, regardless of which is actually weighted more, from a ship design point of view the preferences of priority for Acquisition Costs and Lifecycle Cost are very close. (It is acknowledged that other factors, including contractual constraints and

[3] This paradox was named for Kenneth Arrow, Nobel laureate in economics with work in utility theory.

appropriations methods, influence the priority scheme in practice.)

Several other design factors were investigated at a somewhat deeper level of detail and the results of these are listed in Table 2. The Arrow Paradox is a case in hand to illustrate that the complexity of assessing multivariate group preferences can often result in paradoxical or shaded results. When the “one-on-one” comparison of variables is expanded to many simultaneous comparisons, this complexity is increased by the fact that variables can be somehow interdependent and can be interpreted differently by each respondent. For example, combat capability and survivability, though different, do have a high degree of dependence, as do habitability and manning, or mobility and availability. After seeing that Ship Mission Performance was the most strongly preferred factor of the previous example, the assessment of “combat capability having an average weight of “only” 22.7 points out of 100 may therefore be misleading.

A better indicator of priorities is to look at ratios of preference for the various factors. For example, combat capability was, on average, preferred over construction time by a 22.7 to 2.8 ratio, which is higher than the one-on-one preference ratio of roughly 4:1. Thus, when many considerations are made simultaneously, though the numbers may be diluted, one can see the dominant priorities and their relative preferences emerge within that given context.

DESIGN PRIORITIES BREAKDOWN

FACTOR	AVG %	STD DEV
ACQUISITION COST	15.1	13.0
AVAILABILITY	7.3	6.9
COMBAT CAPABILITY	22.7	11.4
CONSTRUCTION TIME	2.8	2.8
DISPLACEMENT WEIGHT	3.3	3.7
ENERGY USAGE	2.7	2.7
GROWTH MARGINS	3.8	3.3
HABITABILITY	2.6	2.4
LIFECYCLE COSTS	10.0	8.4
MANNING	4.1	3.5
RISK MINIMIZATION	4.5	4.1
STANDARDIZATION	3.9	4.3
SURVIVABILITY	11.0	7.9
OTHER:	6.2	5.8

“OTHER” includes Signatures. Seekeeping. Mobility. Endurance. CAD designability. Modular Construction. Follow Ship Cost. and Environmental Protection factors.

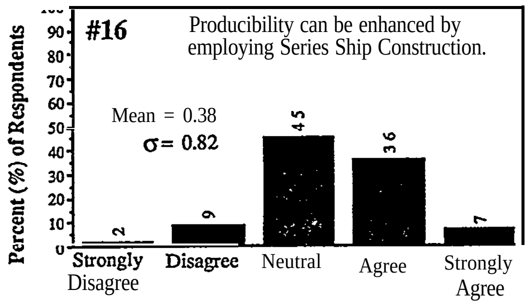
Table 2

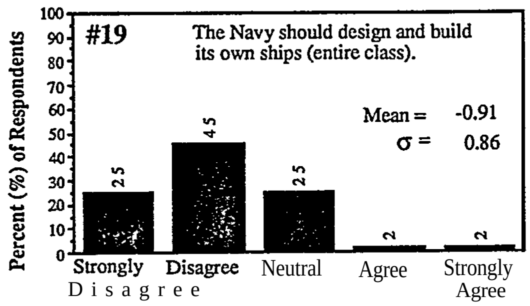
In this survey, these dominant priorities seem to be Combat Capability, Acquisition Cost, Survivability, and Lifecycle cost. Availability and Risk Minimization are also noticeably important to NAVSEA designers. The remainder are, though not the most important, still significant, as are the respondent-suggested factors. “OTHER” includes Signatures, Seakeeping, Mobility, Endurance, which were suggested as possibilities on the questionnaire, plus respondents’ suggestions which included CAD applicability, Modular Construction allowances, Follow Ship Cost, and Environmental Protection factors. The ‘costs paradox’ arises again with this assessment results giving a 3:2 ratio for Acquisition Costs over Lifecycle costs.

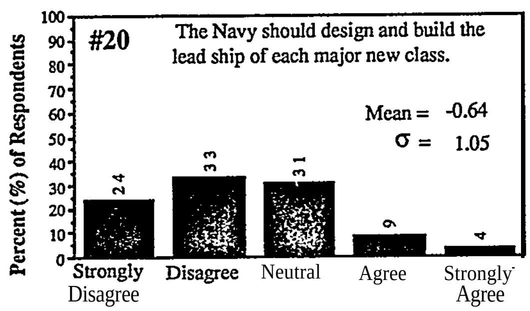
More general policy options were presented in statements 16 through 23. The response to the effect of acquisition budgets was given in statements 17 and 18 previously, with a reduced acquisition budget bringing a negative response, but increased budgets bringing an inconclusive response.

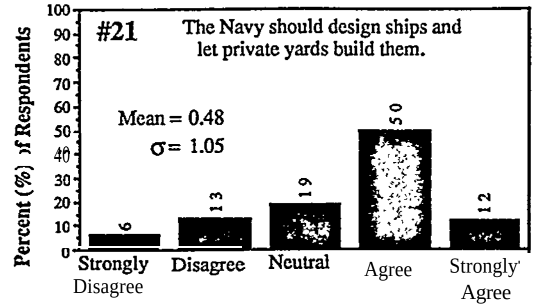
Other statements address general NAVSEA build and contract strategies. Statement 16 shows a large segment of neutral response (45%) to the premise that Series Ship Construction will help ship producibility. Of the

remainder, most (43%) agree that it will. The large neutral response may reflect uncertainty involved with pinning down the responsible factors of a successful shipbuilding program, while the agreement among the remainder may reflect a belief that construction learning curves and associated benefits do enhance ship producibility.

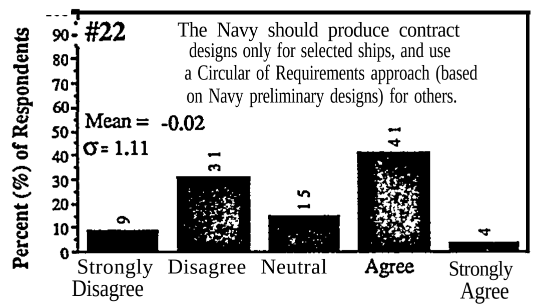


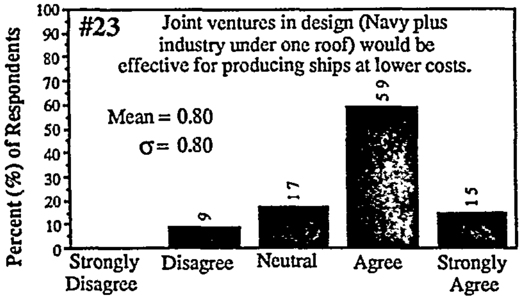




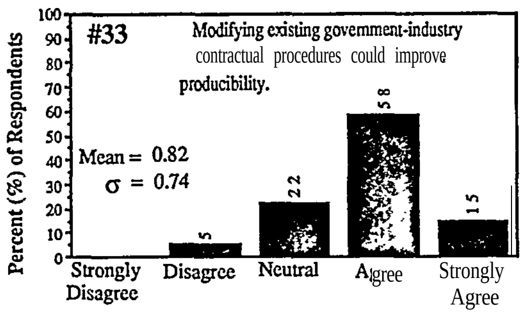


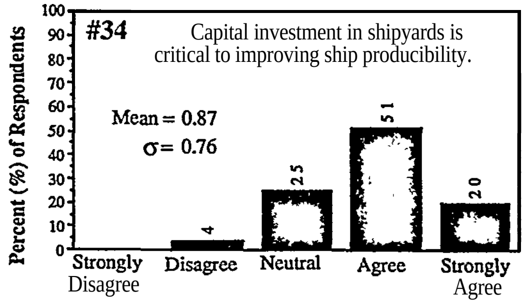
Statements 19, 20, and 21 reflect the conventional ship acquisition strategy, where NAVSEA designs a ship up to a point, the 'contract design', and then a winning bid shipyard continues the detail design and construction. An interesting alternative is the Circular of Requirements (COR) approach, which drew a bi-modal response in statement 22. Whether the COR approach becomes commonly accepted for any type of ship remains to be seen, but the response shows that it deserves investigation. The very strong agreement (74%) to the statement 23 that joint ventures between the Navy and industry would help lower ship costs supports the need to seriously consider alternatives to conventional acquisition strategy and NAVSEA-shipyard relationships.



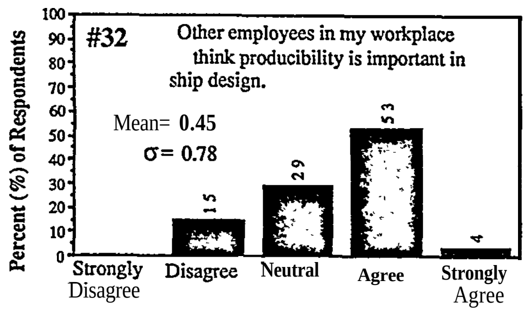


If joint ventures prove to be infeasible in the econo-political environment, some change in operating procedures that help to enhance ship producibility may still be possible. Strong support of modifying existing procedures is shown in statement 33. Addressing another aspect of the economic environment, statement 34 reflects the necessity of U.S. shipyards to update construction methods to utilize modular construction techniques. The 'capital investment' discussed reflects the dependence of ship production on facilities. Whether the the Naval ship market is freely competitive or monopsonistic, it is not in the realm of this paper to discuss investment strategy, responsibility, or possible sources of the investment funds. Of the few comments received, one did say that it should be "private money".





A final policy option is whether producibility awareness and training should be encouraged. Feedback for assessing a general attitude regarding the importance of producibility was sought by statement 32. A reasonably strong agreement that respondents felt that other employees also thought producibility is important is tempered by a significant segment (15%) that sees room for improvement regarding employee attitudes. The policy implication is that communication is necessary to bring all employees into a common consensus regarding producibility because even if it is unintentional, a small dissenting segment can undermine an otherwise coherent force.



Conclusions

The Producibility Survey has helped to identify several areas of agreement and disagreement within the NAVSEA community. There is general agreement that design for production should be part of NAVSEA responsibility, and

that it is important to achieve lower costs. But when specific methods of procedure are approached, disagreement or inconsistency arises. For a team to be successful, its strengths should be used to the maximum extent possible, but also weaknesses should be identified and built up with concentrated effort. In **this light, it** appears that several differences of opinion have been noted.

Areas deserving attention include NAVSEA-shipbuilder relationships, training procedures and producibility design tools, cost models with regard for producibility sensitive parameters, acquisition strategy and a general guidance leading to stronger consensus and communication. The results of the statements on the definition of producibility and the outcome of the design priorities sections, especially the paradox regarding the relative importance of acquisition costs and lifecycle costs, may indicate that a clear policy statement would be useful to give direction to the many NAVSEA employees so that the entire NAVSEA ship design body can work assured it will be making a concerted effort towards a well defined, and consequently better, product.

Several of the opinion statements had bi-modal responses, which represent differences of opinion. Because there is such a diversity of experience within each individual NAVSEA career, each person's opinion may be appropriate from his own perspective. From a management perspective, however, these differences give rise to questions, such as in the case of statement 6, 'Why did some respondents feel there is no contact between NAVSEA designers at early stages of design, **while others** felt there was? What should the consensus response actually be? In statements 7 and 8, effects of shipbuilder involvement on change orders were questioned. Change orders have a significant effect on ship costs, and while many are well justified due to the dynamic nature of design evolution and concurrent development, many may in fact be cost drivers which are not as strongly justified. If any of these can be eliminated by modified NAVSEA-shipbuilder relationships, or by revised acquisition strategies or management policies, these alternatives should be pursued.

Regarding the percentage of high level managers that have had previous producibility experience, is 58% too high or too low? What should it be if this survey is to be taken on a similar group in ten years? If producibility is genuinely important, a higher figure would be desirable.

Acquisition strategy has a high degree of influence on ship producibility. It provides constraints around the design process which may too restrictive for effective design for production. The COR approach had a mixed acceptance, and the concept of joint ventures between the Navy and the shipbuilders was strongly agreed with. Much of this survey has suggested that a high degree of designer-producer interaction is preferable to result in a lower cost product. Because of the relatively low number of shipbuilders available, particularly for sophisticated combatants, a high degree of designer-producer interaction is possible. As technological barriers to producibility are eliminated, the organizational and political ones may be the bigger challenge.

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

Paper presented at the NSRP 1990 Ship Production Symposium,
Plister Hotel, Milwaukee, Wisconsin, August 21-24, 1990

Political Changes in Eastern Europe and the World Shipbuilding Market

8B-2

Dr. Boris S. Butman, U.S. Merchant Marine Academy

ABSTRACT

The recent political and economic events unfolding in Eastern Europe have brought about changes that are of vital importance to the world shipbuilding community. Following in the footsteps of Yugoslavia, already the No 3 shipbuilding power in the world, these countries view shipbuilding as a source of very needed hard currency, and also as a way of generating employment. The relatively loy cost of ship construction together with an adequately developed level of technology, and comprehensive engineering support, make these communist countries serious competitors. Moreover, the announced reduction of the Sovict military budget might free up substantial capacities for export ship construction, and sharply reduce Soviet orders in their former satellite countries, thus making them available for foreign orders. The following paper addresses shipbuilding organization and capacities in the communist countries, advantages, problems and possible forms of business relations with their shipyards.

contents

1. WORLD SHIPBUILDING MARKET: CURRENT STATUS

During the 1980'S decade of bargain prices resulting from a sharp decline in new ship orders, the combined shipbuilding workforce of Japan, South Korea and Western Europe shrank by over 303,000 workers. By the beginning of 1989 the world shipbuilding capacities have been reduced from 37.5 million gross registered tons (GT) to about 18.0 million [1]. Over 75 shipbuilding and ship repair facilities closed in the U.S. alone. Bv 1990 the world-wide shipbuilding capacity had been reduced sufficiently to give the world shipbuilding community a potentially-manageable control over the market.

According published estimates [1], the projected annual demand for new construction in 1990-94 in the range of about 14-16 million GT or 12-25 % below the estimated shipbuilding capacity, which promises a substantial improvement of the current order book and increased prices. The level of new ship construction for 1995-99 is projected to be 21-24 million GT likely resulting in even larger demand and higher prices. Actually, the orders and prices are already climbing up, but whether this trend will continue into the 1990's depends to a large degree upon the developments in the economic 'and international marketing postures which arise from the dramatic political changes being experienced in the communist, or for some of them, the former communist countries.

2. SHIPBUILDING FOR EXPORT IN COMMUNIST COUNTRIES

The share of these countries in world shipbuilding is already quite

substantial. Four out of the eleven largest shipbuilding countries in 1989 were Yugoslavia (No 3), China (No 9),, Poland (No 10) and Romania (No 11), and their combined tonnage of ships on order reached 13,5% to the total world order book **[3].** Since 1978 these four socialist countries together have more than tripled their share of the world tonnage on order. Yugoslavia and Romania began building ships for foreign, "non Soviet", owners more than 20 years ago, almost immediately after they split with the U.S.S.R.' They have managed to maintain, ever since that separation, practically the same number of newbuildings per year while the average ship's tonnage is gradually increasing. I--
I

The People's Republic of China has embarked on the export shipbuilding path only recently, and in a few years has grown to become a substantial shipbuilding power with a share in the world market, reaching over 5% of total number of ships on order.

As per table 1, the other East European countries, currently in the process of severing their traditional ties with the Soviet Union, also possess considerable shipbuilding capacities. As of June 1989, East Germany and Bulgaria had on order all together 71 ships with total tonnage of about one million DWT. At the same time, total tonnage on order the Communist countries 7,130 thousand DWT which accounts for over 17% to the world level.

Table 1 Ships on Order in the Communist Countries

Country	'1987		1989	
	Number of ships [Ref. 2]	DWT (000)	Number of ships [Ref. 31]	DWT (000)
Bulgaria		53	**39**	**505**
Czechoslov.	6	18	*na*	na.
China	37	834		
E. Germany	15'	133	**56**	**1,165 450**
Poland	94'	945	**49**	1,139
Romania	19	339	**38**	1,111
USSR	14	285	51	2,230 529
Yugoslavia	52	1,968		
Total		**5,085**		7,129

Based on the data in Table 1 the Soviet Union does not appear to be a real shipbuilding power, with only **18** ships of 529,000 DWT on order in 1989. The explanation to this misleading data lies partially in the limitations of the statistical analysis, which apparently does not consider the many large river ships over 2000 DVT and tug/barge trains of 5ooo-10,000 DWT, which are very popular in the Soviet Union. However, the main reason is in the vast naval orders, overloading the Soviet shipbuilding capacities. A recent attempt to create a 6OO-ship Wavy in the U.S. has provided our major yards with a substantial backlog. Eased on various counts, the Soviet Navy is 2.5 to 3 times larger. Considering a corresponding doubled and tripled number of naval auxiliaries, and also the #correspondingly large volume of overhauls and -modernizations, it can be appreciated that required shipbuilding capacities in the Soviet Union exceed those available for the American Navy by at least three times.

The driving forces behind the success of Yugoslav shipbuilding are similar to those found in all other communist countries, especially, now when they are struggling to convert into market economies. First of all; there is the ever present shortage of hard currency needed to repay previous debts to Western banks, to finance future industrial projects, and to pay for *grain* and other food related imports in the case of the USSR and China,

Unable to compete with Western democracies due to the low quality of most 'of their industrial products, the communist countries are realizing that construction of simple ships like tankers and general cargo carriers is the easiest way t0 enter the highly competitive world market of industrial products. They also view shipbuilding as a way of maintaining labor employment during the transition period while switching over to the market system.

The recent political events in the East European countries have brought to life various actions affecting world shipbuilding:

1. open-door policies adopted by these countries *when* giant deals like the recent Pepsico agreement become feasible;

2. incredible drive to earn hard currency resulting sometimes in accepting newbuilding sale prices which are far below the actual cost;

3. gradual secession of their economies from the Soviet economy and an end to the barter trade relations.

A reduction by 14.2% of the Soviet military budget and by 19.52 of the

annual production of weapons and military equipment during 1989-90 announced -- michael Gorbachev might have a "snow ball" effect on world shipbuilding. It would:

1. free up substantial Soviet shipbuilding capacities for commercial ship construction for both domestic and foreign owners;

2. sharply decrease Soviet orders placed in their former satellite countries thus' making them available for, foreign owners; and

3. further reduce the --- already limited Soviet orders to West European and Far Eastern! shipbuilders, making that share of shipbuilding capacity available for other sales.

The gradual increase in the share' of naval shipbuilding at Soviet yards in the 1950-60s was accompanied by the, steady diversion of non-military orders placed with foreign yards. Actually, many foreign yards, especially those in the warsaw Pact countries (East Germany, Poland, Czechoslovakia, Hungary,. Bulgaria, and Rumania) have completely replaced the portion of Soviet yard capacities occupied by naval construction.

3. THE YUGOSLAV PHENOMENON

It was the first communist country that broke with the Soviets and decided to explore an independent course of development. Over 30 years ago the country started a program of export oriented shipbuilding. The main driving force was and still is the need for hard currency, In order to win the market, shipyards were forced to match South Korean prices. As a result, prices dropped as far down as $25 million for a 140,000 DWT crude carrier of 1985-90 delivery [4].

In Yugoslav shipbuilding we see a remarkable example of the competitive capabilities of a communist country. Recent issues of marine related periodicals have devoted a considerable amount of time and attention to the subject [5, 6 and 7]. Yugoslavia has maintained the number 3 spot in the world shipbuilding order book for four consecutive years. moreover, their market share in terms of ship tonnage has doubled, and while it was achieved, the composition of the shipbuilding output changed from being primarily tankers and bulk carriers to more diverse and advanced designs. In 1989 the five major yards delivered 23 ships totaling over 900,000 DWT.

The present order book includes a number of modern designs ranging from 140,000 DWT tankers, 40,000 DWT product carriers to 1OO- and 40-ton cranes and 2,000 HP harbor tug boats. Among the deliveries of the last three years are two 3,500-car carriers with a high degree level of automation, providing a potential manning level of eight crew, series of eight rail ferries for the Caspian Sea, large multi-purpose reefers; and Baltic cruise ferries.

Twenty years ago, the JADRANBROD Shipbuilding Association was founded to represent and coordinate the efforts of the major shipyards on the Adriatic Coast. Although -a government-Controlled entity, similar to the Soviet ministry of Shipbuilding, the JADRANBROD, as well as the shipyards themselves, enjoy substantial independence. The four major shipyards are the ULJANIK in Pula, the country's largest shipbuilder, the 3 MAj yard in Rieka, the Brodsplit yard in Split, and the JLM yard in Trogir (See Fig. 1).

The Uljanik yard, with a workforce Of 8,000. with two 173 meter and 135 meter long shipbuilding berths is capable of constructing ships up to 160,000 DWT on the larger berth. It also has a diesel plant to build MAN B&W and Pielstic engines, and an electrical factory with licenses from Siemens and ESAB.

The 3 Maj yard is a combination of a three-berth shipbuilding facility with capacities of up to 150,000 DwT, and a modern diesel plant, building the newest Sulzer design engines under the license agreement. The Split Yard with four building berths and 5,000 employees has most diverse portfolio and delivery history, including very large crude and bulk carriers, 2,200 passenger/car ferry, reefers, and product carriers.

The forth major shipbuilding yard, the JLM at Trogir, specializes in floating docks, mid-size product carriers, and harbor tugs.

Another large shipyard, the Victor Lenac in Rieka, is the major repair and conversion facility which has floating docks with up to 24,000 tons lifting capacity.

with all its shipbuilding successes, Yugoslavia remains a state run economy, plagued with all of the familiar drawbacks and shortcomings: planning flows and material shortages, lack of incentive on the part of the workforce towards the improvement of productivity, political instability and labor unrest, and high inflation. However, the main lesson to be learnt is

that all of the inherited problems have not prevented the government-controlled economy from gaining a substantial share of the world shipbuilding market. It should not be forgotten, however, that state run economies do have one advantage, namely, the ability to keep labor cost low. But with the current changes taking place in the world today, it is doubtful how long this will continue.

4. SHIPBUILDING IN EASTERN EUROPE AND CHINA

There exists a substantial body of literature dealing with shipbuilding capacities in the East European Communist Countries and China. The following is a brief summary of the available information.

China

Although only a decade ago it was practically unknown as a shipbuilding power, China today competes today for the No 3 spot *in* the world order book; From the creation of the People's Republic of China in 1949 up until 1979; the Chinese shipyards built 4.61 million DWT of total tonnage for their own merchant fleet, or about 150,000 DWT per year. They built 3.5 million DWT in the next 7 years, including over one million DWT for foreign shipowners [8, 9].

For many years, China, like the USSR, has set aside a substantial portion of its shipbuilding capacities for naval construction. The naval build- slowed down a few years ago when China launched; its dramatic economic reforms. After adoption of the open-door policy in the mid-eighties, the growth of industry accelerated, especially with regard to the export portion of industrial output. Thus, the shipbuilding industry enjoys a steady annual increase in the order book oF over 10%.

The details of the organizational structure of China's shipbuilding industry are very similar to that of the USSR. The industry is managed by the China State Shipbuilding Corporation (CSSC), a Government entity, embracing 26 shipyards, 60 machinery plants and over 70 institutions, factories and shops with a total of almost 300,000 employees. Among the institutions under the CSSC umbrella there are about 35 design and research centers employing over 40,000 personnel [10].

The seven major shipyards capable of building ships of 30,000 DWT and above are located along the East China Sea and Yellow Sea Coasts in Dalian, Shanghai (3 yards), Guangzou, and Chunhua. All of those shipyards are heavily involved in export activities, Among the recent deliveries from these shipyards are two car carriers for 3,700 vehicles each, a 2,700 TEU containership with reefer capacity, two 81,350 DWT Superflex 3 Class multi-purpose ships, and two 118,000 DWT shuttle tankers, [11].

The prevailing types of Shipbuilding installations are the traditional inclined end-launching berth and a side-launching berth. Only the Dalian shipyard, the largest in the country with 15,000 employees, has a gravel dock to build ships Up to 150,000. DWT. In addition, this yard has three smaller berths - 290, 255 and 185 meters long. A 350 meter long building dock for: ships up to 300,000 DWT is scheduled to be completed in 1991. Dalian shipyard, as well as the Hudong and Shanghai: yards, operate full-scale diesel plants building Sulzer, B&W MAN and Pielstic. designs under license agreements.

CSSC also offers 24 drydocks at 17 shipyards around the country, capable of lifting ships up to 60,000 DWT.

Last year's political turmoil in China adversely affected the Shipbuilding industry: number of new orders dropped immediately and delays with new deliveries were reported. However, recent new orders have significantly improved the situation, securing a bright future for the Chinese shipyards.

Poland

The four major Polish shipyards in Gdansk (two yards), Gdynia and Szczecin (fig.1) have been enjoying a very steady market of new building for the USSR for over 40 years. Since 1949, Polish shipyards have finished about 1,000 ships, and most of them were sold to the USSR. The Warskv shipvard in Szczecin alone has built over 200 ships on Soviet orders.

However, the advantage of this steady and reliable demand has to be weighed against the fact that the transactions are carried out entirely on the barter basis. The Soviet Union pays for ships with raw materials, and the prices for these supplies do not reflect current world level. Moreover, many components for the ships are purchased by Poland from the Vest for dollars, and are not reimbursed upon ship delivery. At the same time it should be remembered that significant modernization plans also require hard currency. As a result, in spite of the many advantages of dealing with the USSR, including steady

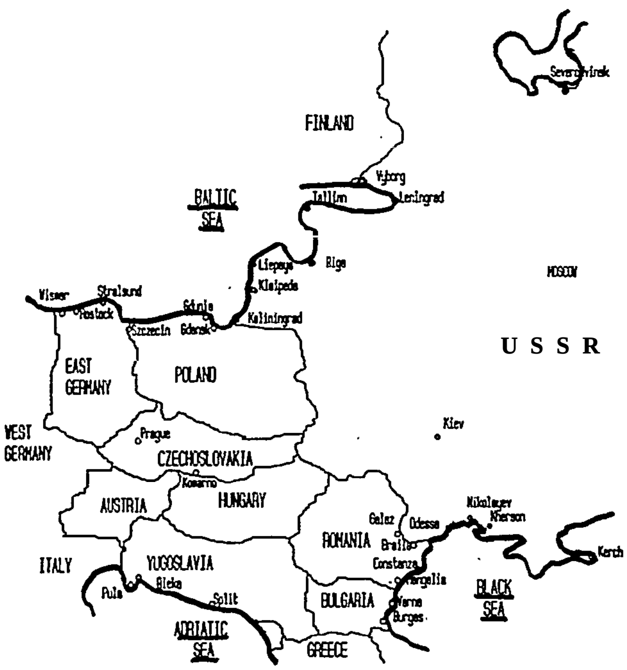


Fig. 1 Geography of Shipbuilding in Eastern Europe

demand and long ship series, Polish. shipyards are turning towards western shipowners in search of hard currency.

Tic recent political and economic' changes in poland support the western orientation of the shipbuilding industry. Shipyards now operate under the umbrella of CENTROMOR, a combined venture of the Government, shipyards and marine equipment plants, which covers, all aspects of the export and import of ships and marine equipment [13].

Among the ships built recently by' the CENTRONOR group are floating docks, large passenger/car ferries, 85,000 DWT tankers , 150,000 DWT bulk carriers from Gdynia, 29,000 DWT bulk lumber carriers, and fish factory trawlers from Gdansk, car/pa ssenger ferries, 32,000 DWT bulk carriers, and 30,000 DWT product carriers from Szczecin.

There have been, however, a few cases of substantial delays and late deliveries which led to the cancellation of contracts or reduction of the number of ships ordered. The main reason for these failures have been labor shortages and pure personnel discipline. Although the total shipbuilding workforce exceeds 50,000 people, many experienced workers left shipyards during and after the labor unrest of 1980-81, and a significant proportion of the remaining workers are still heavily involved in political activities. The problem is so serious that at one time the very existence of the Polish shipbuilding industry was in doubt.

As of January, 1933 all three major shipyards had the order books filled until 1992-93. The future will show if the industry is able to restructure and operate successfully without Government subsidies [14].

East Germany

. The four major East German., shipyards in Wismar, Rostock, Stralsund, and Warnemunde have full order books until 1991-92, largely due to a steady demand from the USSR. Only 15% of the annual output is intended for the western countries. East Germany faces the same problems as Poland when dealing with Soviet orders. not surprisingly, the yards are actively looking for Western business, and their marketing strategy is changing towards a more aggressive promotion of their products and services.

One of the main selling points for East Germany has been to emphasize their notable domestic designs: various fishing and fish-factory ships, a 18,000 DWT multipurpose container ship with a Sulzer engine manufactured in East Germany, a 1,200 TEU container ship with a MAN engine also built domestically, and a two-deck rail ferries for Baltic Sea. Recent deliveries include many high technology ships like icebreaking ro/ro's, sea-going and river -sea passenger liners [15].

East German shipyards have full, order books until 1992, but these came largely from the USSR, and there is a significant probability that most of them will not materialize. In the very near future, East German yards will be incorporated into the mighty West German shipbuilding system, and wi11 become much less attractive for the USSR as they loose the opportunity for bartered payments, and for Western shipowners ho will no longer be able top take advantage of low wage rates.

Other East European Countries

Recent political developments have created a confusing and unclear situation in Bulgaria and Romania, which both have their major shipbuilding facilities on the east coast of the Black Sea (Fig. 1). The three large Bulgarian yards in Varna and Burgas, and the five shipyards in Romania (Constanza, Galatz, Braila, Mangalia,

and Turnu Severin) enjoy a steady flow of orders from the USSR, China and the Comecon countries. The political changes will diminish the traditional ties with other Communist countries, and the need for hard currency will become a major factor. These countries can offer facilities and expertise to build primarily bulk carriers and tankers of all sizes. from small river-sea types up to 160,000 DWT (Constanza)

The two shipyards in Czechoslovakia (in Prague and Komarno), build mainly specialty river ships: self-propelled dredges, floating pump stations of passenger ships, and river-sea cargo carriers.

5. SOVIET SHIPBUILDING SYSTEM

The Soviet Union has not just imposed its own political system upon the East European countries; it also forced upon them the principles of Soviet style central planning and management. Their Soviet Union brought these countries under the umbrella of Comecon (Council for Mutual Economic Assistance), where the Soviet management system is prevalent. The Soviet Union used its colleges and universities to educate and train the leading engineers and managers of these countries. Therefore, the organizational structure of shipbuilding in most of East Europe and even in China, closely resembles that of the Soviet Union. The following short description of the Soviet shipbuilding organization [see also 16]

Shipbuilding Production Associations - one of the latest inventions of the Soviet economy management think tank. It is aimed at a reduction in administrative personnel) improvement of planning, and also represents an attempt to ease the excessively tight strings which are imposed by the central planning system. A shipbuilding association is normally formed by merging a major shipyard with one or several smaller yards and assigning additional manufacturing facilities to them, such as a foundry, a machine shop, an electrical factory, other factories and shops, and engineering institutions.

The eight major shipyards have already been : typical full service enterprises capable of fabricating and building not only ship's hull, piping and foundations, but also various fittings, some auxiliary and even propulsion machinery, including steam boilers. The ship production association has substantially expanded capacities to produce more ship components, clearly an advantage under the Soviet material distribution system. Examples of ship-building associations include the one in Kherson, the Admiralty Association in Leningrad, and the Astrakhan Shipbuilding Association.

From the standpoint of assignment and production structure, there are three major types of shipyards in the Soviet Union: 1) naval, 2) commercial, and 3) mixed production. For a majority of shipyards, their assignments are generally unchanged for a long period of time. For example, the Admiralty Association is mainly a naval yard with occasional orders for special commercial vessels, like the first nuclear icebreaker, Lenin, while the Leninskaya Kuznya in. Kiev. is mainly a fishing vessel yard with limited involvement in naval construction. The largest mixed production yards, which appear to be the backbone of both naval and commercial shipbuilding in the Soviet Union, have been gradually moving toward deeper involvement into the naval area during the last two decades.

Based on the variety of shipyards available, and on the steady demand for new ships, narrow shipyard specialization has become an important feature of Soviet shipbuilding. Series construction creates the optimum condition for those yards. Among other advantages it allows them to reduce the negative impact of centralized planning on construction time, and reduces the cost of subcontracted works.

western naval experts are familiar with most fixed assignments of the Leningrad and Nikolayev yards for the construction of large combatant vessels (cruisers, aircraft carriers, large destroyers), Severodvinsk and Komsomolsk for submarines, Tallinn for destroyers, and Liepava and Kaliningrad for smaller combatants. In the same way, commercial construction is assigned to various yards according to their capacities and experience (see Fig. 1):

- large tankers:- Kerch' (after 1975), Admiralty and Baltic yards in Leningrad (before 1970);
- midsize tankers - Kherson;
- small sea-going, sea-river, and river tankers - Volgograd, Gorky, Astrakhan', Tumen' and some other inland yards;
- large dry cargo carriers - Vyborg, Baltic and Zhdanov (Leningrad), Ocean and Black Sea (Nikolayev), Kherson;
- midsize and small dry cargo carriers - Gorky, Navashino, Astrakhan', krasnoyarsk,

Petrokrepost', Gorokhovets, Konsomol'sk Khabarovsk, etc.;

ore and bulk carriers - Ocean (Nikolayev) ;

reefer carriers - Baltic (Leningrad), Ocean (Nikolayev);

fish travlers - Black Sea and Ocean (Nikolayev), Leninskaya Kuznya (Kiev), Klaipeda;

fishing factories - Admiralty (leningrad), Black Sea (Nikolayev);

passenger vessels and ferries - Zhdanov (Leningrad), Gorky:

- drilling rigs - Vyborg.

Actually, the eight largest yards (Kerch, Kherson, and three each in Leningrad and Nikolayev) are capable of building any type of ships, with very limited prior preparation. Therefore, whenever it is required to construct ,a unique or very complicated ship or to start a new series, one of these yards usually receives the order. For example, the unique fishing factory, Vostok, was built at the Admiralty yard; the largest surveillance vessel, yury Gaparin, and the second generation of nuclear-powered icebreakers - at Baltic yard; and giant whale factories - at the Black Sea yard. Similarly, these sane yards are usually used for startinga a new series of large naval vessels.

6 SOVIET MARITIME EXPANSION And SHIPBUILDING

The USSR came out of WWII with a very small fleet of two million DWT total tonnage consisting mainly of very old, or second hand lend-lease and reparation vessels. By the late fifties the overall tonnage had increased to about three million DWT. But during the next 10 years the fleet grew almost live-fold to the level of 15 Million DWT to occupy tile 6th spot in the world ranking [17].

Growth has continued up to the present, although at a slower rate. While in the 60s they added primarily General cargo ships of simple design, in the eighties their growth was of a selective type: most of the new orders were either to replace older vessels, or to satisfy special needs. The latter were mainly ships capable of carrying out certain auxiliary naval functions (ro/ro, ferries, oil product carriers, research and hydrographic ships). Another special assignment of a new ship was, and still remains, the aggressive participation in the world ocean trade and competition with the traditional carriers on the major profitable lines. Most of these special ships were ordered from the European communist countries, while more sophisticated ships like icebreakers, reefers, and certain container carriers, were built for the USSR in Western Europe.

As of 1986, the number of Soviet ships- on-order exceeded 150. It grcw to 139 in 1988. and to 210 as of January 1990. while number of Soviet ships on order constituted over 15% of the total' world order book, their share by tonnage was only 3% According to various Soviet 'publications and official interview, there is no further substantial planned growth of their Merchant Marine for the near future.

The analysis shows that the Soviet fleet (currently holding the fifth spot in the World Maritime ranking with its almost 25 million DWT) is capable of meeting most of the water transportation needs of the Soviet economy. Therefore, the decision regarding a further increase of the fleet size depends on the evaluation of the three other functions of the Soviet merchant fleet: to earn hard currency; to support the Navy, serving actually as the Navy's {auxiliaries; and to provide transportation of cargoes to and from so-called "friendly nations".

The scope of the first function 'should be determined by a comparative 'economic analysis of profitability of shipbuilding for foreign owners versus ship acquisition from foreign and domestic yards for international trade. The odds appear to favor shipbuilding for the foreign owners. The Pepsico-Soviet deal supports this conclusion. As apart of the agreement Soviet shipyards build for Pepsico at least ten commercial ships, ranging in size from 28,600 DWT to 65,000 DWT, with the total value in excess of U.S. $ 300 million, that will later be sold or leased in the international markets [18].

The size of the merchant fleet required to support the Navy's operations can only be determined after the final points of the Soviet commitment regarding the military budget reduction are set. However, due to the severe economic conditions of the country, a decision to limit the Naval assignment of the merchant fleet night be taken independently and much earlier.

The urgent need for hard currency might accelerate this move. The latest political events as well as statements of the Soviet leaders suggest that their attitude to the "friendly nations" is gradually changing. There is much less

tonnage needed to support sharply reduced Soviet aid deliveries to Nicaragua Angola and Vietnam. There are 'also indications of revaluation of the Soviet-Cuban economic relations which might free up many of the 163 ships that are used on the route to and from Cuba through a substantial period of the entire year [19].

7. ADVANTAGES OF BUSINESS, Relations information WITH COMMUNIST COUNTRIES

The low price of newly built ships is the main attraction for the shipowner t0 enter a business relation with a shipyards in a communist country. These countries manage Western or Japanese competition because 'their production cost is much lower Moreover, the Government ownership of shipyards and policy of subsidization, at times, even allows them to set prices below production cost, as long as the sale is for hard currency. However, it is extremely difficult to carry out a decent cost analysis of Soviet shipbuilding because they still censor all the vital data related to ships and shipyards in spite' of all changes inspired by the perestroika". Hence, the limited information presented below is a result' of the author's analysis, evaluation and sorting of the data obtained from' various Soviet official and unofficial, Sources and publications [20, 21 and 22].

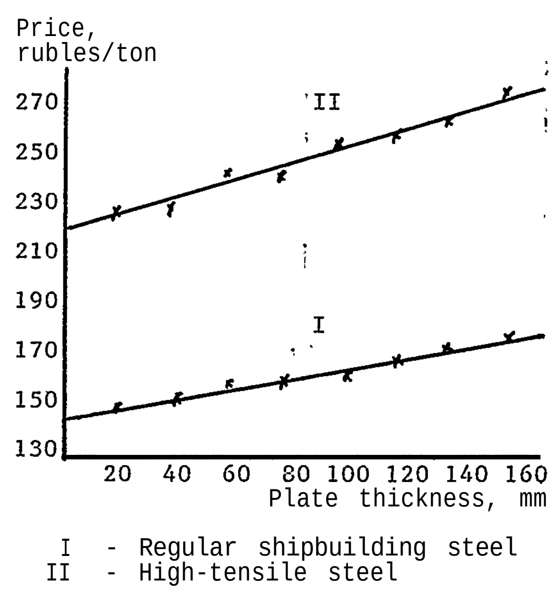
The share of major components of production costs for the representatives of various types of ships built at Soviet shipyards is presented in the Table 2.

Table 2 Production Cost Structure

Ship Types	Material %	Labor Cost %	General Exp. %	Subcontr. %	Others %
'General Cargo	22	9	20	43	6
Tanker	36	9	20	28	7
Ro/ro	20	8	21	44	7
Barge Carrier '(Nuclear)	13	8	22	47	10

Material 'costs are composed of steel, propulsion plant, auxiliaries, and other materials. The USSR is the largest producer of steel in the world, and their prices are the lowest by far Fig. 2 shows 'list prices for steel plates in rubies per ton, which vary depending on steel quality and plate thickness.

The official Government exchange rate is one ruble for U.S.$l.5 which is artificial and not based on purchasing power parity. Moreover, the Soviet Government has recently announced a special business exchange rate of one 'U.S. dollar for six rubles, although, it is not clear if they intend to use it in all commercial transactions. Even based on the official rate, the average cost of U.S.$300/ton appears extremely low.. A reasonable assumption would be additional premium of at least 50% applied for special brands of high tensile steel. And it is also obvious that the price for steel, as well as for any other materials and components



'Fig. 2 List Prices for Steel Plates

intended for use on foreign orders, would substantially differ from those used on the internal market. It has been. for years a practice of strict separation of the internal market from, the export activities in pricing and financing area, as well as, in material supply system.

The general policy of the shipbuilding industry in Communist countries is to buy as littLe. as, possible from the foreign vendors in order to save hard currency to maintain lower production costs. The' Soviet industry itself is capable of producing practically any component of a ship, including diesels, turbines, all auxiliaries and electronics. Low labor rates and low costs of basic materials contribute to a very competitive cost of production.

Major diesel factories in Poland, East Germany, Czechoslovakia, and several plants in the USSR including those in Leningrad and Bryansk manufacture the entire range of marine engine types and sizes. In general, quality is the main problem of the industry, and of diesel manufacturing, in particular. The recent production and technology improvements combined with licensing the best designs from Sulzer and MAN/B&W might help them. to become competitive in the world diesel market. The decisive advantage of Soviet and Cast European diesels, as well as other marine machinery, is the fact that their price is below world market level.

The main variable in construction expenses is labor cost, which in turn is dependent on labor rates and consumption. A rough estimate of total labor consumption for the construction of a cargo carrier, 160 m long and 12,000 ton of light weight, at a typical Soviet shipyard, is equal to about one million man-hours, or about U.S.$1.'5 million for total direct labor cost. Another interesting price parameter is production cost per one man-hour of labor consumed. The average value for this parameter is 13 rubles, however, it sets just an approximate value, because real cost depends on vessel class, yard particulars, etc.

cost of production labor is a function of labor rates, fringe benefits, insurance and other related charges, and labor productivity. The Soviet labor rates are among the lowest in the world: one man-hour of average skilled labor costs in the range of .60 - 1.25 rubles. Using the official rate of exchange, it equals to approximately U.S.Sl.50: with the more practical rate U.S.$1.00 for six rubles the average labor cost is estimated as U.S.$0.2O per one man-hour.

The cost 0f design and production engineering support comprises substantial portion of the overall production cost. Communist countries, and especially the Soviet Union, are capable of providing quite adequate service for the lowest price. The Soviet Union, for instance, has created a huge multi-tiered educational system which contributes a great deal to the shipbuilding industry.

More than twenty schools - universities, colleges and academies - offer 5-5 year engineering programs in marine related fields including marine, electrical, radio and electronic engineering, as well as naval 'architecture. Several thousand engineers. join the shipbuilding and repair enterprises every year. Therefore, it is not unusual to find that 5-103 of the overall workforce at a given yard are specialists with engineering, certificates or diplomas. Their salaries, however, are very close to those of the production workers in the area of 150-200 rubles or $225-300 per month [18].

The development of an efficient shipbuilding organization is one of the principal areas of engineering and scientific studies in the Communist countries. The following essential factors have contributed significantly to the success of these studies: high level of standardization; extensive experience in employing various management methods based on detailed planning of all activities; constantly growing demand for products of shipbuilding; and strong support by a vast engineering and scientific community.

For instance, the modular system of ship construction is seen in the USSR as one of the most significant break-throughs *in* the organization and management of ship construction. The modular system is based on standardization, group technology principles, zone outfitting, vast experience in the block/section method of vessel hull forming, and on the process lane concept. One of the first practical applications of modular principles appears to be the highly publicized construction of a series of KRYM-class super tankers of 150,000t DWT in Kerch' and the subsequent PODEDA-class series.

3. PROBLEMS AND DEFICIENCIES

The product quality is an Achilles tendon of shipbuilding production in Communist countries, especially in the Soviet Union. It *is* reflected in poor

workmanship, inadequate appearance of compartments and accommodations, a high level of machinery and equipiment wear, more frequent failures, and excessive warranty claims.

The quality of products is the major concern of their research and engineering institutions, and also of special quality service departments of the shipyards. For instance, to the individual Soviet shipyard a unique RITM Engineering and Production Association has been created in the USSR: a combination of the midsize Petrozavod shipyard in Leningrad with the Leningrad Engineering Institute for Shipbuilding Technology. This government financed association employing hundreds of engineers and production workers has been given the task of developing and manufacturing new ship production equipment and tooling for use in Soviet shipyards. The goal of this effort is productivity and quality increases.

To the advantage of the Soviet, East European and Chinese shipbuilders, many shipowners are still maintaining :a "built cheaper" approach without proper regard for future operational and maintenance expenses. While crew reduction and fuel saving considerations are normally a part of an evaluation of a proposed shipbuilding project, the maintenance and repair costs and the corresponding losses of operational time are not yet taken properly into account.

The absence of thorough studies on the subject is the main reason that whole life cycle evaluations are not done on a regular basis It would have been very interesting to carry out a comparative study on maintenance and repair costs for comparable ships built in different countries, as was done in a very informative study conducted by Prof. H. Bunch regarding ship construction costs in the U.S., Japan and China [12].

The time needed to construct the ship affects general production expenses, expected profits of the shipowner, and also the amount of interest payments to the mortgage holder. The Soviet and East European yards are at obvious disadvantage compared with their Western or Japanese counterparts. Due in large part to inefficiencies of central planning in the USSR, and its legacv in Poland, Bulgaria, Romania and Yugoslavia, the construction time significantly exceeds that of, for instance, Japan.

9. Conclusion

Low cost of shipbuilding, a decent technology level, and comprehensive engineering support suggest that some kind of a business involvenent with a shipyard in a communist country might prove profitable for an American Shipowner. The question for this audience is whether American shipbuilder can benefit from business relations with Communist countries. In the opinion of this author, there are a few avenues to follow:

1. A management agreement might be welcomed by a certain Soviet, East European or Chinese shipyard that is struggling to gain needed experience in how to operate in a free market world, how to incorporate the modern computer based management methods, and how to deal with quality problems.
2. Subcontracting a shipyard in a communist country to fabricate hull structural modules (cheap steel and high expertise in welding at Soviet shipyards), various auxiliary machinery units and installations.
3. Subcontracting a shipyard for a partial or even complete construction of a ship under the condition that all managerial (ship management., project management, scheduling, etc.), certain material and equipment procurement, quality control and some engineering functions are carried out by an on-site team of the general contractor.
4. Hiring or subcontracting an engineering institution in a communist country, for instance, in the Soviet Union, to carry out certain studies (naval architectural, marine and electrical engineering, etc.), prepare a proposal, conceptual or/and detailed design. Incidentally, the Krylov Scientific Research Institute, a Soviet counterpart of the David Taylor R&D Center, offers foreign shipbuilding companies the opportunity to study the hydrodynamic properties of new designs in their 625 and 218 meters long towing basins.
5. Various types of joint ventures including a partial ownership of shipyards and machinery shops in the Communist countries.

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